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# ACQUISITION RESEARCH
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**Analyzing Cost, Schedule, and Engineering Variances on Acquisition Programs**

**16 December 2011**

**by**


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**LCDR Michael R. Schilling, USN**

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**This study of cost, schedule, and engineering variance (CV, SV, and EV) data identified in the Selected Acquisition Reports (SARs) of acquisition programs indicates that early program variances are significantly associated with future program variances. An enhanced understanding of CV, SV, and EV interrelationships and the connection between these program variances and the cost and schedule Earned Value contract variances will allow program managers to better understand the full programmatic impact of a variance problem. This understanding could also aid future researchers in identifying best practices in recovering from the identification of such a problem. In addition, the identification of CV, SV, and EV differences across Major Defense Acquisition Program (MDAP) types highlights the connection between segments of the defense industry and the development of best program management practices. This research first examines the data using traditional descriptive statistics in order to determine whether identifiable patterns exist among MDAPs and their associated contracts. A primary objective of the analysis is to develop empirical models that employ cross-sectional, time-series data contained in the SARs. These models help explain the full effect of fixed-price incentive R&D contracts within MDAPs on cost and schedule variance during both engineering and manufacturing development (EMD) and production and deployment. It is anticipated that this analysis will also help close any existing gaps in the understanding of program versus contract management data.**

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# ANALYZING COST, SCHEDULE, AND ENGINEERING VARIANCES ON ACQUISITION PROGRAMS

## ABSTRACT

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
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| AoA | Analysis of Alternatives |
| ACAT | Acquisition Category |
| ACWP | Actual Cost of Work Performed |
| APB | Acquisition Program Baseline |
| APUC | Average Procurement Unit Cost |
| BCWP | Budgeted Cost of Work Performed |
| BCWS | Budgeted Cost of Work Scheduled |
| BENS | Business Executives for National Security |
| CAE | Component Acquisition Executive |
| CBA | Capabilities-Based Assessment |
| CDD | Capabilities Development Document |
| CDR | Critical Design Review |
| CJCS | Chairman of the Joint Chiefs of Staff |
| CLIN | Contract Line Item Number |
| CPAF | Cost-Plus-Award-Fee |
| CPFF | Cost-Plus-Fixed-Fee |
| CPIF | Cost-Plus-Incentive-Fee |
| CV | Program Cost Variance |
| DAB | Defense Acquisition Board |
| DAES | Defense Acquisition Executive Summary |
| DAMIRS | Defense Acquisition Management Information Retrieval System |
| DAU | Defense Acquisition University |
| DCR | DOTMLPF Change Recommendation |
| DFARS | Defense Federal Acquisition Regulation Supplement |
| DoD | Department of Defense |
| DOTMLPF | Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, or Facilities |
| EAC | Estimate at Completion |
| EMD | Engineering and Manufacturing Development |
| EV | Engineering Variance |
| EVM | Earned Value Management |
| FAR | Federal Acquisition Regulation |
| FASA | Federal Acquisition Streamlining Act of 1994 |
| FFP | Firm-Fixed-Price |
| FOC | Full Operational Capability |
| FPDS | Federal Procurement Data System |
| FPI | Fixed-Price Incentive |
| FPIF | Fixed-Price Incentive Firm |
| FPIS | Fixed-Price Incentive Successive |
| FRP | Full-Rate Production |
| FY | Fiscal Year |

| | |
|---|---|
| GAO | General Accounting Office (before July 7, 2004); Government Accountability Office (after July 7, 2004) |
| ICD | Initial Capabilities Document |
| INCOSE | International Council on Systems Engineering |
| IOC | Initial Operational Capability |
| JCIDS | Joint Capabilities Integration and Development System |
| KPPs | Key Performance Parameters |
| LRIP | Low-Rate Initial Production |
| MAIS | Major Automated Information Systems |
| MDA | Milestone Decision Authority |
| MDAP | Major Defense Acquisition Program |
| MDD | Materiel Development Decision |
| MS | Milestone |
| ORD | Operational Requirements Document |
| PAUC | Program Acquisition Unit Cost |
| PDR | Preliminary Design Review |
| PPBE | Planning, Programming, Budgeting, and Execution |
| R&D | Research and Development |
| RDT&E | Research, Development, Test, and Evaluation |
| SAR | Selected Acquisition Report |
| SBIRS | Space-Based Infrared System |
| SEI | Software Engineering Institute |
| SEM | Structural Equation Modeling |
| SV | Schedule Variance |
| TDS | Technology Development Strategy |
| TRL | Technology Readiness Level |
| USD(AT&L) | Under Secretary of Defense for Acquisition, Technology, and Logistics |
| WBS | Work Breakdown Structure |
| WSARA | Weapon Systems Acquisition Reform Act of 2009 |

# I. INTRODUCTION

## A. OVERVIEW

The current policy climate in the federal government is one of increasing fiscal austerity. The Department of Defense (DoD) spent approximately $500 billion on contracted goods and services in fiscal year (FY) 2010, of which $135 billion was spent on procurement. Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) Ashton Carter released a memo in September 2010 providing guidance for how the DoD could achieve an estimated $100 billion in management and contracting efficiencies over the course of five years (Carter, 2010). Decreasing budgets will require acquisition professionals to do more with less.

The Government Accountability Office (GAO, 2011) reported the FY2008 portfolio of 96 Major Defense Acquisition Programs (MDAPs) collectively ran $303 billion over initial program budget and were an average of 22 months behind schedule in delivering initial capability. The analysis of cost variance (CV), schedule variance (SV), and engineering variance (EV) differences across MDAPs could highlight defense acquisition industry segments with program management best practices. If not attributable to program management practices, differences across MDAPs could point to differing levels of technology insertion risk or system integration complexity.

As acquisition professionals have attempted to increase efficiency and examine current contracting practices, one area of interest has been contract type. There has been a new emphasis within the acquisition community to increase the amount of fixed-price contracts. At one time, the DoD attempted to impose fixed-price incentive contracts on efforts in which significant invention could be anticipated, although recently the use of cost-plus-award-fee contracts has become widespread (Carter, 2010). Under Secretary Carter advocated the use of fixed-price incentive firm target contracts in the place of cost-plus-award-fee contracts wherever practicable (Carter, 2010).

According to Table 6.8 of the *National Defense Budget Estimates for FY2012* (Under Secretary of Defense [USD] Comptroller, 2011), also known as the DoD

Greenbook, research and development (R&D) contracts for FY2010 totaled $80 billion. Increasing the number of R&D contracts issued on a fixed-price incentive basis could cause significant savings based on the presumption that fixed-price incentive contracts decrease cost overruns. During the engineering and manufacturing development (EMD) phase of programs, contracts funded through research, development, test, and evaluation (RDT&E) are of particular interest because they represent the last stage in which large cost-plus contracts are typically awarded. However, restricting R&D work to a fixed-price incentive basis could negatively affect the detection and solving of problems early in a program.

Contracted companies may stop researching all problems and alternatives in order to increase their profit margin on the fixed-price incentive contracts, provided that the contract specification requirements are satisfied. Properly constructed incentives may mitigate the risks of contractors' scope of research for a materiel solution, but quantitative incentives may not be able to motivate all the desired behaviors. Deficiencies in the identification of MDAP problems could increase costs in the long term. For example, if a contractor eliminated tests during RDT&E to save money for the company, then it could result in increased expenses to the government to fix the unidentified problems in the future.

### 1. Impact of Acquisition Failures on the Warfighter and the Public

Cost overruns and schedule delays have a significant impact on the warfighter and the taxpayers. Deputy Secretary of Defense William J. Lynn III (2009) stated,

> American taxpayers and our men and women in uniform are understandably skeptical when they hear promises to reform the Defense Department's sprawling acquisition system, which often delivers major weapons systems to our troops years behind schedule and billions of dollars over budget.

There have been numerous studies that have focused on improving defense acquisitions, but the DoD repeatedly experiences the same problems; cost and schedule growth have continued over the last 30 years regardless of all the acquisition reforms, congressional studies, and DoD reports repetitively highlighting the same issues (Schwartz, 2010). These include specific studies of successes (Dillard & Ford, 2009) and spectacular

failures (General Accounting Office [GAO], 1992), as well as more systemic reforms (Department of Defense Authorization Act, 1982; DoD, 2011). The aim of these efforts was to improve elements of the acquisition system, but they have not effectively addressed the reinforcing relationships present between fiscal constraints, state-of-the-art technical requirements, and the acute needs of the government, as explored in the discussion of risk by acquisition phase in Chapter II of this research.

Program oversight generally addresses specific problems and not the process as a whole. Accordingly, it is extremely difficult to balance the pressures exerted by different reporting requirements over a program's life cycle; it is possible that these reporting requirements, intended to improve acquisition outcomes, may decrease the probability of program success due to their onerous nature (Wood & Moseley, 2011). As a report from Business Executives for National Security (BENS, 2009) stated, "Defense acquisition revolves around 15-year programs, 5-year plans, 3-year management, 2-year Congresses, 18-month technologies, 1-year budgets, and thousands of pages of regulations" (p. 1). Despite heavy oversight, the DoD continues to manage programs that are delivered late and that experience cost overruns, all while additional layers of oversight are inserted.

### 2. History of Acquisition Failures

The current management problems that acquisition programs face include the failure to control costs and schedules. According to Defense Acquisition Specialist Moshe Schwartz (2010), "More recently, concerns over defense acquisitions have centered around significant cost overruns, schedule delays, and an inability to get troops in the field the equipment they need when they need it" (p. 13), but acquisition and contracting failures are a persistent problem. During the Civil War, President Abraham Lincoln forced Secretary of War Simon Cameron to resign due to corruption and mismanagement of contracting in the War Department (The Lincoln Institute, 2011). The calamity of acquisition management has existed in the United States military since the Civil War, and as long as there are contracts, contracting oversight failures will be difficult to eliminate. Mitigating the cost and frequency of oversight failures through the

sound use of contract- and program-level indicators of future variance may offer some relief from these failures.

### 3. Importance of Research and Development

R&D activities are necessary to develop many technologies used in warfighting systems. R&D directly contributes to program success by demonstrating successively higher levels of integration and realism in a system's or subsystem's technology. This increasing level of demonstrated ability eliminates some technical risk. R&D for some systems and components begins before Milestone (MS) A. The R&D discussions in this research focus on later system R&D, specifically during the EMD acquisition phase.

### 4. Current Acquisition Climate

The proposed 2010 defense budget accounted for 20% of the federal budget, of which one third was for defense acquisitions (BENS, 2009). In July 2011, Congress debated cutting $866 billion from the defense budget over the next ten years (Ewing, 2011). By comparison, the DoD requested a budget authority of $671 billion for FY2012 (USD Comptroller, 2011). The DoD spends approximately $400 billion a year on contracted goods and services (Carter, 2010). It appears the DoD must continue satisfying more requirements with similar budgets, or as Under Secretary Carter (2010) says, "do more without more" (p. 1).

## B. PURPOSE

Our purpose in this research is to identify the presence of failure or success indicators before the production phase for DoD acquisition programs using both program and contract variances. To identify the indicators influential in program failure or success, we examine the variances during the production phase by analyzing statistical relationships of preproduction program and contract variances. We determined these relationships by examining the impact of cost, schedule, and engineering variances during research and development to later period variances of program execution.

CV, SV, and EV within individual programs have only been qualitatively linked. Under Secretary Carter (2010) noted,

> As all programs compete for funding, the usual result is that a program settles into a level-of-effort pattern of annual funding that does not deviate much from year to year. The total program cost is the level-of-effort times the total length of the program. Thus a one-year extension of a program set to complete in 10 years can be expected to result in a 10 percent growth in cost as the team working on the project is kept on another year. (p. 4)

Further understanding the interrelationship of CV, SV, and EV could allow program managers to better understand the full programmatic impact of a cost, schedule, or technical problem during EMD. Identifying outliers that defy the norm of a positive CV, SV, and EV reinforcing loop could also aid future researchers in identifying best practices in recovering from a program cost overrun, schedule slip, or technical deficiency. A reinforcing loop exists when CV, SV, and EV interrelate and cause each other to continuously rise in a reinforcing, rather than stabilizing, manner. The cost and schedule variances that are part of the earned value contract reports in SARs may also be linked to the program-level variances.

Performing a quantitative analysis on program and contract variances could provide statistical predictions of future effects. The results will help at all levels of program management, including during the initial programming of requirements. The results will also show which contract and program variances have the greatest effect, thereby helping program managers to prioritize which variances to give their finite attention. Beyond this, formulating and estimating this linkage will enhance understanding of programs and contracts and will close gaps between the closely related acquisition communities of program management and contracting.

## C. RESEARCH QUESTIONS

The problems with MDAPs running over budget and behind schedule gave rise to several research topics that must be investigated. Of particular interest to us was the increased use of fixed-price contracts recommended by the DoD and the effects of contract variances on program variances. In order to focus these general research topics, we proposed the following questions.

### 1. Primary Questions

1. What effect does fixed-price R&D have on production cost, schedule, and technical performance?

2. Do different segments of MDAPs (e.g., fighters, tanks, missiles, satellites) exhibit differing cost and schedule growth?

3. Does early CV, SV, or EV serve as a leading indicator of later-period CV, SV, and/or EV in either EMD or post Milestone C?

### 2. Secondary Questions

1. What portion of MDAPs have fixed-price incentive R&D contracts?

2. Is there qualitative information to support the assertion that fixed-price contracts during the EMD phase hinder the identification of program problems?

3. If the effect of fixed-price R&D is measurable, are the variances larger with regard to cost, schedule, or engineering during EMD and production?

4. Based on the results found in this research, can any definitive policy recommendations be made?

## D. SCOPE AND METHODOLOGY

In this research, we include the following: (1) a review of general acquisition CV, SV, and EV performance; (2) an in-depth review of the effect of fixed-price R&D during EMD on program CV, SV, and EV; and (3) a discussion of the interrelationships of CV, SV, and EV. We conclude this research report with a recommendation for R&D contract type and a discussion of the implications of overall CV, SV, and EV performance.

In this research, we first examine the available archival MDAP data using traditional descriptive statistics in order to determine whether identifiable patterns exist among contracts within MDAPs. This analysis helps close existing gaps between our understanding of program management and contract management. In order to perform this analysis, we collected cost, schedule, and engineering variance data, including post MS C production and deployment phase data, for 31 MDAPs from Selected Acquisition

Reports (SARs) for multiple years. The database consists of cross-sectional, time-series data. The cross-section includes multiple programs and their attendant contracts during a particular year. The time-series consists of individual programs and their attendant contracts identified by year over a several-year period. We use this dataset, when combined, for cross-sectional, time-series analysis, also known as panel data analysis (Princeton University, 2007).

Following the descriptive statistical analysis, we employ a linear multiple regression analysis that combines cross-sectional, time-series SAR data by examining the effect of specified explanatory variables on an outcome measure. Additionally, we propose future research using structural equation modeling (SEM), a method that allows the simultaneous analysis of multiple factors. SEM analysis permits the inclusion of conceptually constructed variables that underlie the measurable variables, thereby, helping to explain the full effect of fixed-price incentive R&D contracts within MDAPs on later period cost and schedule variance during the production and deployment phase. The use of a structural equation model would allows others to examine variance in ways not previously available; that is, it would allow the consideration of multiple, interrelated, and simultaneously varying factors, such as the cost, schedule, and engineering variances of a program and the earned value cost and schedule variances of that program's contracts.

As indicated, our objective in this research is to determine the likely effects of the increased usage of fixed-price R&D contracts during EMD on long-term program cost, schedule, and engineering variances. Although we give SARs particular emphasis, we also utilize DAES reports and Federal Procurement Data System (FPDS) data from the Defense Acquisition Management Information Retrieval System (DAMIRS). The methodology we used in this research consisted of the following steps:

1. conduct a literature review;
2. collect historical data from DAMIRS;
3. build a database that includes both program data and contract data by year, with all required fields in sufficient number for analysis using SPSS (a

statistical package that permits cross-sectional, time-series analysis of measurement variables);

4. conduct a descriptive statistical analysis;

5. complete an initial model for CV, SV, and EV;

6. complete an initial model pooling of CV, SV, EV, and other relevant program, cost, and schedule contract variances measured in dollars;

7. conduct a thorough investigation of the program and contract variances using regression analysis to identify explanatory variables that influence these measures; and

8. prepare a recommendation regarding R&D contract type selection.

## E. ORGANIZATION OF STUDY

In Chapter II (Background), we provide an explanation of the current DoD acquisition process, the DoD acquisition categories, and different contract types. We provide a summary of the relationship between contract types and the acquisition phases, and a description of the possible risk experienced during different phases of a program. In this chapter, we also include sections discussing the importance of R&D along with technology readiness levels.

In Chapter III (Purpose), we provide explanations of the regulations that govern acquisition variances and aid in the decision-making of acquisition professionals, including the Nunn-McCurdy Amendment, Acquisition Program Baselines (APBs), SARs, and Earned Value Management. We include a definition of each of the program and contract variances utilized in this research. We also provide in Chapter III the information required to understand program- and contract-level variances, including program cost, schedule, and engineering variances, as well as contract earned value cost and schedule variances. We conclude the chapter with an explanation of why the study of these acquisition variances is important.

In Chapter IV (Database Construction and Analysis), we describe the process we used to collect data and to perform the analysis of variance. The chapter contains the

steps we followed, including our data collection methods and the use of descriptive statistics.

In Chapter V (Statistical Methodology and Results), we provide an explanation of our methodology and analysis. The regression analysis methodology is discussed. This analysis, conducted using cross-section, time-series methods, should be viewed as exploratory, and certain aspects of our results need to be interpreted in this light. This includes our methodology for cross-sectional, time-series analysis. Our analysis includes identifying the relationship between preproduction program and contract variances, and future program variances. The interrelationships we describe will help acquisition professionals better understand both the effects of cost, schedule, and engineering variances on programs, and the linkage between programs.

In Chapter VI (Summary, Conclusions, and Recommendations), we explain the findings of our research and discuss the implications of the findings to practitioners. We then draw conclusions based on those results. We also provide recommendations for future research efforts and disclose the limitations of the study.

## F. BENEFITS OF THE STUDY

We anticipate that this research will help acquisition personnel develop a better understanding of program and contract cost and schedule variances, and possibly provide indications of future program cost increases to establish better management techniques. Understanding the implications of fixed-price incentive R&D acquisition programs on cost, schedule, and engineering variances will help the DoD set appropriate policies for contract type in the early stages of system development. In this research report, we provide the first comprehensive analysis of the relationship between program data and contract data. One reason why understanding this relationship is so important is that problems with cost growth and schedule slippage are typically reported at the program level but the contract type applies at the contract level, and a program may contain several different contracts during both the EMD phase and the production phase. This research will also help the DoD more appropriately consider the long-term impacts of

proposed procurement cuts and will help leaders determine the best structure of those cuts. It may also improve system delivery time to the warfighter.

# II. BACKGROUND

## A. OVERVIEW

In this chapter, we provide the background information required to understand the scope of this research, including a review of the DoD acquisition process and three decision support systems. We briefly explain federal contract types applicable to acquisitions, along with the preferred contract types for each phase of the DoD acquisition process. Then, we explore the importance of R&D to acquisition program success, and we discuss technology readiness levels. The risk associated with contract type and acquisition phase is reviewed. We conclude the chapter with a discussion of the primary documents from which the study draws data.

## B. DEFENSE ACQUISITION PROCESS

In this section, we provide an overview of the DoD acquisition process and the three principal decision support systems: the Planning, Programming, Budgeting, and Execution (PPBE) process; the Joint Capabilities Integration and Development System (JCIDS); and the Defense Acquisition System. These three integrated systems ensure acquisition personnel make consistent decisions to efficiently acquire the right products and services required by the warfighter. The DoD's decision support systems, described in the *Defense Acquisition Guidebook* (DoD, 2011), and its policies, oversight, and integration can be seen in Figure 1. The boxes in Figure 1 annotate the direct supporting references for each system. The overlap in the three systems can clearly be seen in the figure and is important to understanding the balance of all three systems in the defense acquisition process.

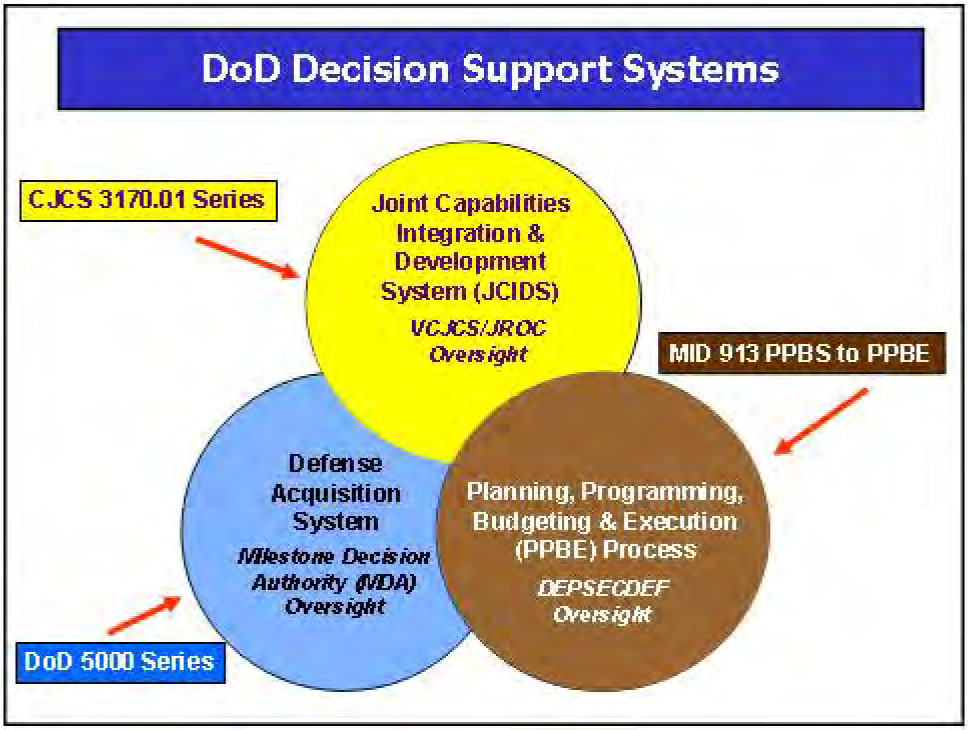


**Figure 1. The DoD Decision Support Systems**
(DoD, 2011)

### 1. The Planning, Programming, Budget, and Execution (PPBE) Process

The PPBE process provides for strategic planning, program development, and resource determination. The PPBE process generates funding appropriations to support DoD acquisition requirements. During this process, the Secretary of Defense provides priorities, which guide resource allocation decisions. Program managers must be aware of this process to effectively manage the funding of contracts. Failure to recognize the link between budgets and requirements in the acquisition process may directly result in poor performance during the acquisition process (Gansler, 2002).

Accurate program estimates are important in order to obtain necessary funding during the budgeting process. The timing of funding availability is also important and could significantly affect program schedules and costs. In an address to the Senate Armed Services Committee regarding the FY2011 Continuing Resolution, Secretary of Defense Robert Gates stated that the failure of timely funding would damage

procurement and research programs, causing delays, increasing costs, and disrupting production of highly demanded assets (Gates, 2011).

### 2. Joint Capabilities Integration and Development System (JCIDS) Process

The PPBE process receives development and production life cycle estimates from the requirements defined in the Joint Capabilities Integration and Development System (JCIDS) process. JCIDS procedures support the Chairman of the Joint Chiefs of Staff (CJCS) and the Joint Requirements Oversight Council (JROC) in determining joint military capability needs. JCIDS is the DoD's systematic means for appraising gaps in military warfighting capabilities and for proposing solutions to solve those gaps. Announced in 2003, the JCIDS process changed the way requirements were identified—replacing Service-centric requirements processes with a joint capabilities system. The change came after Secretary of Defense Donald Rumsfeld sent a memo that stated,

> Please think through what we all need to do ... to get the requirements system fixed. It is pretty clear it is broken, and it is so powerful and inexorable that it invariably continues to require things that ought not to be required, and does not require things that need to be required. (CJCS, 2006, p. 5)

The elimination of the word *requirements* from the generation system signaled the DoD's intent for the JCIDS process to determine possible procedural or training-based solutions (non-materiel solutions) available along with materiel solutions and to justify the need for the capability (CJCS, 2006).

The JCIDS process is covered in CJCS Instruction 3170.01G (CJCS, 2009) and is summarized here to provide for an understanding of the requirements review process in defense acquisitions. The process implemented in JCIDS supports the management of resource investments and must be performed prior to the acquisition process for new systems to begin. Figure 2 illustrates the acquisition process and what documents are produced during the JCIDS process in order to identify gaps in capabilities (CJCS, 2009). As seen in Figure 2, various parties are involved in the process and are required to produce multiple coordinating documents.

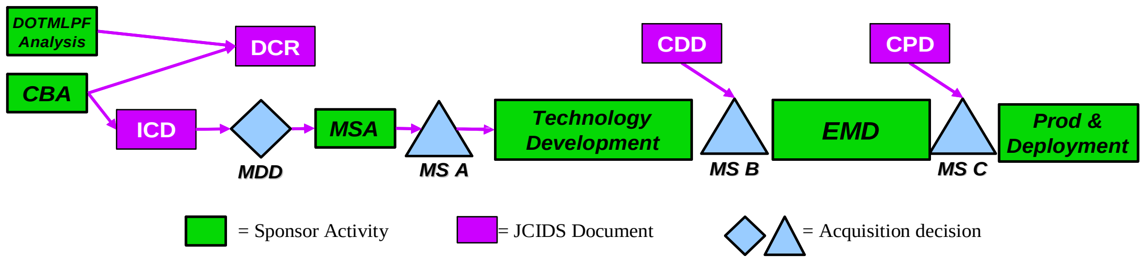


**Figure 2. JCIDS and Defense Acquisition**
(CJCS, 2009)

The JCIDS process incorporates the military missions and the capabilities required to perform the operational objectives associated with these missions. The incorporation of capabilities into the JCIDS process originates through a capabilities-based assessment (CBA) and an identified valid gap in mission requirement. As stated by General McChrystal,

> If only non-materiel solutions are recommended or a non-materiel solution can be implemented independent of proposed materiel needs, a joint doctrine, organization, training, materiel, leadership and education, personnel, or facilities (DOTMLPF) change recommendation (DCR) is produced. (CJCS, 2009)

An initial capabilities document (ICD) identifies gaps requiring materiel solutions. An approved ICD provides the required information to form the materiel development decision (MDD) and starts the actual acquisition process (CJCS, 2009; see Figure 2).

### 3. Defense Acquisition System Process

The objective of the defense acquisition system is to acquire products that satisfy specified needs and provide measurable improvements to mission capabilities at a fair and reasonable price (DoD, 2011). Defense acquisition follows distinct program phases, a series of decision points, and significant milestones. The process defined in the DoD 5000 Series that guides acquisition programs for MDAPs is summarized here. Figure 3 illustrates the defense acquisition system process by showing the relationship between each phase and milestone.

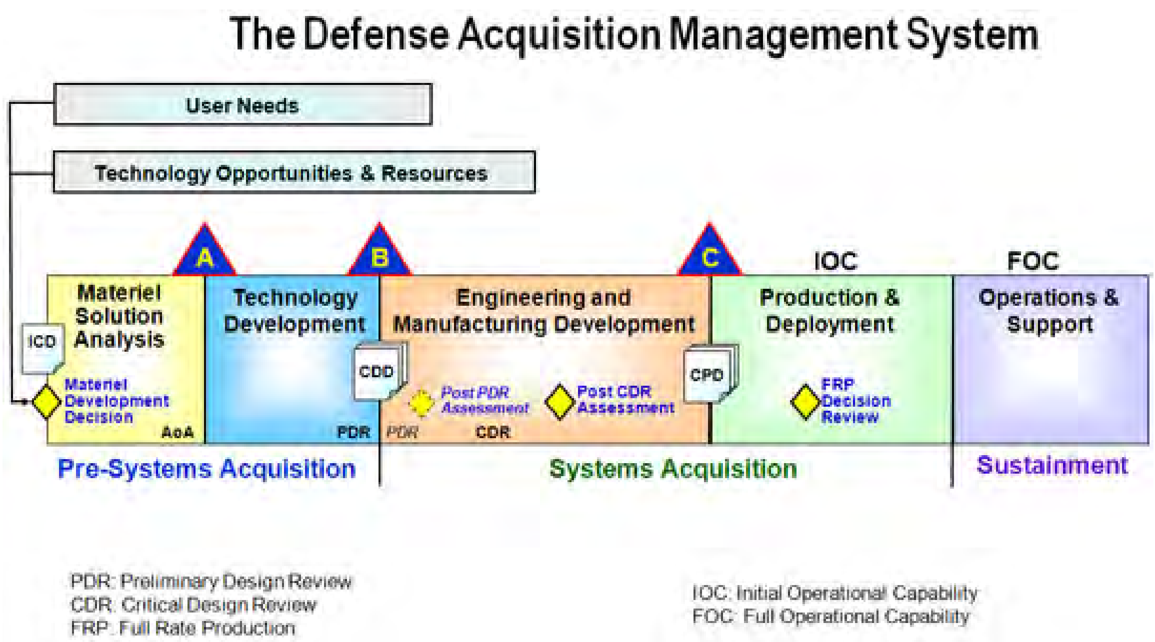


**Figure 3. The Defense Acquisition Management System**
(USD[AT&L], 2008)

#### *a. Materiel Solution Analysis Phase and Milestone A*

After an approved ICD and an MDD, the milestone decision authority (MDA) may authorize entry into the acquisition management system, starting with the materiel solution analysis phase, also known as the concept refinement phase (see Figure 3). For MDAPs, a defense acquisition board (DAB) is formed that provides advice on critical acquisition decisions. The DAB is chaired by the USD(AT&L) and includes senior officials from the Joint Staff, the military departments, and the staff offices within the Office of the Secretary of Defense (OSD). The USD(AT&L) is the MDA when there is a DAB. The purpose of the materiel solution analysis phase is to perform an analysis of alternatives (AoA) for all potential materiel solutions; the phase culminates with a decision about whether to proceed with MS A as designated by the MDA. An AoA assesses each alternative on measures of effectiveness, cost, schedule, concept of operations, and overall risk. The materiel solution analysis phase ends once the MDA approves the results of the completed AoA (USD[AT&L], 2008).

#### *b. Technology Development Phase and Milestone B*

The acquisition decision memorandum is signed at MS A, documenting an approved materiel solution, a technology development strategy (TDS), and entry into the technology development phase. The TDS establishes the preliminary acquisition plan, including the cost, schedule, and performance goals for the engineering and manufacturing development phase. The purpose of the technology development phase is to reduce technology risk and to establish subsystems and components that must be demonstrated before being fully integrated into a system (USD[AT&L], 2008).

This phase is a continuous discovery and development process to identify the accessibility and refinement of the requirement. Competitive prototypes are built based on initial capabilities. The users, or the relevant Service, should establish a capabilities development document (CDD) during the technology development phase that specifies the technical performance parameters required to deliver the proposed design and that fills the capabilities gap identified in the ICD.

The CDD replaced the operational requirements document (ORD) that was used under the old requirements system. The CDD supports the MS B decision and must be approved prior to MS B. It guides the engineering and manufacturing development phase by defining measurable and testable capabilities. The CDD identifies operational performance attributes of the proposed system known as key performance parameters (KPPs). KPPs make up the bulk of the CDD and list each required measure of effectiveness. The parameters contain both threshold (required or minimum) and objective (desired or maximum) performance values (USD[AT&L], 2008).

The program manager should prepare for a preliminary design review (PDR) prior to MS B, as planned by the development strategy. The system developers, engineers, users, and certification authorities should all collaborate to agree on a proposed solution based on demonstrated technology that meets the PDR. The PDR report and the demonstrated manufacturing process are provided to the MDA at MS B to identify projected cost, schedule, and risk. At MS B, the MDA decides to proceed to the

next acquisition phase, perform additional work, or terminate the effort (USD[AT&L], 2008).

#### *c. Engineering and Manufacturing Development Phase and Milestone C*

The engineering and manufacturing development (EMD) phase begins with an approved acquisition strategy at MS B. MS B and entrance into the EMD phase typically mark the initiation of an acquisition program. The purpose of the EMD phase is to develop an integrated system of demonstrated subsystems and components design. In this phase, a proven system capability is also developed, and an achievable and affordable manufacturing process is demonstrated (USD[AT&L], 2008).

The integrated system design defines functionality and interfaces; provides a complete, detailed design; and reduces full system-level risk. The system capability and manufacturing process demonstration assures that the system will operate in accordance with performance parameters and demonstrates that system production can be supported. This phase ends when the system meets all approved requirements, performs in its intended environment, effectively demonstrates manufacturing capabilities, has reasonably available production capabilities, meets MS C requirements, and has the approval of the MDA to commit the program or to terminate the effort (USD[AT&L], 2008).

#### *d. Production and Deployment Phase*

The production and deployment phase is the final phase in the systems acquisition process (see Figure 3). The purpose of this phase, according to DoD Instruction 5000.02 (USD[AT&L], 2008), is "to achieve an operational capability that satisfies mission needs" (p. 26). MS C approval begins the production and deployment phase. MS C specifically authorizes low-rate initial production (LRIP), which is performed at the beginning of the phase. In the past, the production and deployment phase did not begin until the start of full-scale production, at MS III. For the purposes of this research, we considered the beginning of the production and deployment phase as occurring at LRIP approval, even for programs that did not have a milestone review at

that point. We provide further information regarding our data collection methods and analysis in later chapters. During LRIP, manufacturing capability is verified. Initial operational testing and evaluation is performed prior to the point that the MDA authorizes entry into full-rate production and deployment from a successful full-rate production decision review (USD[AT&L], 2008).

### 4. Acquisition Program Categories

Acquisition programs are assigned to an acquisition category (ACAT) based on their location in the acquisition process, on cost, or on whether the program is of special interest to the MDA. The USD(AT&L) can reclassify an acquisition program at any time. The discussion in the following subsections explains the differences between each category.

#### *a. ACAT I Programs*

ACAT I programs, also called Major Defense Acquisition Programs (MDAPs), include programs designated by the MDA as special interest. According to 10 U.S.C. § 2430 (2011), MDAPs are designated by the Secretary of Defense and estimated to require a total expenditure for RDT&E of more than $300 million in FY1990 dollars or for procurement of more than $1.8 billion in FY1990 dollars. ACAT I programs are further divided by decision authority. The programs with the highest interest are ACAT ID, and the MDA is the USD(AT&L). For ACAT IC, the MDA is head of the DoD Component or, if delegated, the Component Acquisition Executive (CAE; USD[AT&L], 2008).

#### *b. ACAT IA Programs*

ACAT IA programs are also called Major Automated Information Systems (MAIS) and, in some cases, meet the definition of an MDAP, but also include programs designated by the MDA as special interest programs. According to 10 U.S.C. § 2445 (2011), MAIS programs are designated by the Secretary of Defense when program expenditures in FY2000 constant dollars are estimated to exceed the following amounts: $32 million for all expenditures directly related to automated information systems

definition, design, development, and deployment costs in a single FY; $126 million for all expenditures directly related to the entire program; or $378 million for all expenditures related to the total life cycle costs. ACAT IA programs are further divided into ACAT IAM, in which the MDA is the USD(AT&L) or his or her designee, and ACAT IAC, in which the MDA is the head of the DoD Component or, if delegated, the CAE (USD[AT&L], 2008). In this research, we examine only MAISs that are also MDAPs.

#### *c. ACAT II and ACAT III Programs*

ACAT II programs do not meet criteria for ACAT I, but they are still major systems with a dollar value in FY2000 constant dollars estimated by the DoD Component Head of eventual RDT&E greater than $140 million or of procurement of more than $660 million. The MDA for ACAT II programs is the CAE or an individual designated by the CAE. ACAT III programs include DoD programs that do not meet ACAT II criteria, and the MDA for these programs is designated by the CAE (USD[AT&L], 2008). We do not directly examine ACAT II and ACAT III programs in this research, although it may be possible to generalize some of the findings of this research to these programs when sufficient similarity in treatment exists.

## C. FEDERAL CONTRACT TYPES

A wide variety of contracts can be used to purchase products and services required by the federal government. A large acquisition program typically has multiple types of contracts, and selecting the right contract type for an acquisition is essential to successful program completion. Federal Acquisition Regulation (FAR, 2011) part 16 describes the different federal contract types. Contracts vary according to the responsibility assumed by the contractor for the costs of performance and the amount and nature of profit incentives offered to the contractor for specified standards or goals (FAR, 2011). For DoD MDAPs and this research, the two general categories of contracts are fixed price and cost reimbursement, but there are other types outside these two categories.

### 1. FIXED-PRICE CONTRACTS

Fixed-price contracts are suitable when acquiring supplies and services that users can describe in sufficient detail. The price is agreed upon during the award phase, or, in appropriate circumstances, an adjustable price may be included. Fixed-price contracts providing an adjustable price may include a ceiling price, a target price, or a combination of both. Under a fixed-price contract, most of the performance and cost risks are placed on the contractor through the use of incentives to control costs (FAR, 2011). The following summaries of the different types of fixed-price contracts are based on FAR (2011) part 16.

#### *a. Firm-Fixed-Price Contracts*

Firm-fixed-price (FFP) contracts are used when a fair and reasonable price can be determined at the beginning of the contract (FAR, 2011). The government pays the negotiated amount regardless of the contractor's actual performance costs. Administrative requirements are not eliminated for FFP, but the burden is reduced. Given well-defined specifications, the contractor bears most of the risk. This contract type is preferred above all others because it encourages the contractor to contain costs (Garrett, 2007). The government prefers FFP if clear objectives exist and accurate pricing data is available, but that may not always be the case.

#### *b. Fixed-Price Incentive Contracts*

Fixed-price incentive (FPI) contracts are used when the government wants to incentivize technical performance and cost controls. Parties can negotiate a target cost, target profit, and a ceiling price that provides for the contractor to assume an appropriate share of the risk. If the contractor reaches the ceiling price as a result of an overrun, the contract essentially becomes an FFP contract. In principle, the contractor is paid no more than the ceiling price and must meet the requirements of the contract. The profit is adjusted by calculating the final price using a formula based on the relationship of final negotiated and target costs. Two different types of fixed-price incentive contracts are authorized: fixed-price incentive firm (FPIF) target contracts and fixed-price incentive successive (FPIS) targets contracts (FAR, 2011). Currently, there is a proposed Defense

Federal Acquisition Regulation Supplement (DFARS, 2011) rule to encourage the increased use of fixed-price incentive contracts. The origination of this rule is credited to a memo sent by the USD(AT&L) on November 3, 2010 (Levin, J., 2011), that gave direction on attaining better efficiency and productivity in defense contract spending. In this study, we analyze this type of contract closely and identify the size of variances occurring with this type of contract compared to other types of contracts.

## 2. COST-REIMBURSEMENT CONTRACTS

Cost-reimbursement contracts allow the government to pay the contractor all allowable incurred costs that are fair and reasonable as prescribed in the contract. This type of contract is used when many uncertainties associated with contract performance and costs cannot be estimated with sufficient accuracy to use a fixed-price contract. A cost-reimbursement contract provides an estimate of the total costs for the purpose of obligating funds, and it establishes funding ceilings that cannot be exceeded without approval from the contracting officer. Contractors may exceed these ceilings at their own risk. Cost-reimbursement contracts are typically renegotiated or terminated if total costs exceed ceilings.

Cost-type contracts place most of the cost and performance risk on the government (FAR, 2011). The contractor should put forth its best effort, but there is no promise of results. The government may not end up with the final product or service it contracted for, but it must reimburse the contractor for costs incurred that do not exceed the approved funding ceilings. The government is obligated to reimburse all actual costs that are allowable, allocable, and reasonably incurred to the extent prescribed in the contract (FAR, 2011). In the following subsections we summarize the different types of cost contracts; these summaries are based on FAR (2011) part 16.

### *a. Cost-Plus-Fixed-Fee Contracts*

Cost-plus-fixed-fee (CPFF) contracts pay a pre-determined, fixed-fee that is agreed upon during contract negotiations. The fee may be adjusted for changes in the work to be performed (FAR, 2011). The contracting officer is responsible for monitoring

the contractor's expenditures and can request an audit of the contractor's vouchers at any time, similar to other cost-reimbursement auditing.

#### *b. Cost-Plus-Incentive-Fee Contracts*

Cost-plus-incentive-fee (CPIF) contracts are used to encourage contractors by providing greater profits through cost savings and other performance improvements. The government pays allowable, reasonable, and allocable costs and an incentive fee based on the contractor's achievement of the objectives calculated by using a formula that is based on the relationship of total allowable and target costs. The contract specifies target costs and target fees and establishes minimum and maximum fees and a fee-adjustment formula. The increase or decrease in fee is intended to incentivize the contractor to effectively manage costs (FAR, 2011).

#### *c. Cost-Plus-Award-Fee Contracts*

Cost-plus-award-fee (CPAF) contracts are used to provide additional incentives to contractors to achieve excellence in areas such as quality, timeliness, technical ingenuity, and cost-effective management (FAR, 2011). The government pays allowable costs, a base fee, and an award fee based on a subjective evaluation of performance. The contract provides for interim rating periods during contract performance. It is possible that the inclusion of KPPs in an MDAP's CDD at MS B may induce the program manager to incentivize KPPs through the use of award fee incentives (Hildebrandt, 2010) since award fees offer the ability to incentivize ambiguously defined objectives.

## D. TYPICAL CONTRACT TYPE BY ACQUISITION PHASE

The government can use a wide variety of contracts to order required products and services. Selection of the contract type is driven by risk considerations (FAR, 2011), which vary among programs and across acquisition life cycle phases (Garrett, 2007). Certain contract types are more suited to certain types of acquisitions and certain stages of the acquisition life cycle (FAR, 2011; Defense Acquisition University [DAU], 2008). No particular contract type is the answer for any phase, but enduring trends in selection

of contract type exist due to the limitations typically present during each life cycle stage. Preferred contract types for a phase may shift over time due to changing policy or guidance or to shifting practitioner preference based on research regarding programs of a similar nature. As we explain in more detail later in this section, contract type is ultimately a collaborative decision between a program's contracting officer and program manager, subject to negotiation with a program's contractors (FAR, 2011; DFARS, 2011).

### 1. RISK AND PREFERRED CONTRACT TYPE

Fixed-price contracts are typically preferred by the government to minimize its risk, but they may not be appropriate if the work lacks precise specifications or cost estimates. FAR (2011) subpart 16.101 characterizes contract types as those ranging "from firm-fixed-price, in which the contractor has full responsibility for the performance costs and resulting profit (or loss), to cost-plus-fixed-fee, in which the contractor has minimal responsibility for the performance costs and the negotiated fee (profit) is fixed." If funding ends before completion, the contract should be renegotiated or terminated. Incentive contracts fall in between these two extremes. Fixed-price incentive and cost-plus-incentive-fee contracts should only be considered if it is in the government's best interest to use cost and, when appropriate, performance incentives (FAR, 2011).

Cost estimates are ultimately predictions about the future, and they are subject to error (Garrett, 2007). Buyers and sellers understand that error is present in cost estimation. For the purposes of this research, we consider the government the buyer and the contractors the sellers. The government is wary of accepting an excessive cost for goods or services, and contractors seek to ensure that they do not suffer a loss on a sale. Each party attempts to hedge against its own risk. Contractors estimate pessimistically, and the government estimates optimistically, resulting in a "range of possible costs" (Garrett, 2007, p. 106).

Whenever practicable, the government's default option is to use a firm-fixed-price contract, but this is frequently not possible. If a large amount of estimating uncertainty is present, the government and a contractor may be unable to reach an agreement without

the government accepting an excessively pessimistic cost estimate. This results in the government negotiating with a contractor to establish the contract's type and price. This negotiation often results in the government sharing cost risk with the contractor to bring down the contracted price, although achieving a more reasonable price is not the sole objective. The objective of this negotiation "is to negotiate a contract type and price (or estimated cost and fee) that will result in reasonable contractor risk and provide the contractor with the greatest incentive for efficient and economical performance" (FAR, 2011, subpart 16.103). Selection of contract type can be depicted as a trade-off between the buyer's risk (risk to the government) and the seller's risk (risk to the contractor), as shown in Figure 4.

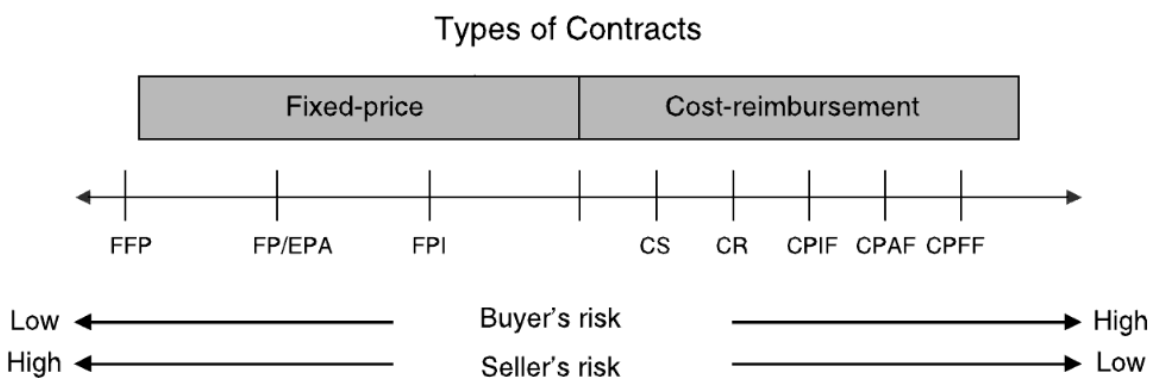


**Figure 4. Types of Contracts by Risk**

This figure from Garrett (2007, p. 127) was altered to fit the context of this research, federal MDAPs. Accordingly, the Time and Materials contract type was eliminated from the graphic; although it is a permissible federal contract type, it is not significant with respect to MDAPs. The Cost Plus Percentage of Cost contract type was also eliminated because, by law, this contract type is no longer permissible for federal contracts.

## 2. RISK BY ACQUISITION PHASE

During the beginning stages of system acquisition, risk is typically higher. System acquisition risk is initially driven by a lack of program definition and by uncertainty regarding the program's ability to meet scheduled technical achievements.

CDD is an attempt to change this. From a contracting perspective, risk can be understood as poorly or undefined requirements driving uncertainty in performance cost. When looking beyond a contracting risk perspective, acquisition risk can be understood as a combination of four factors: technical risk, cost risk, schedule risk, and programmatic risk (Blanchard & Fabrycky, 2006).

Technical risk is the possibility that a technical requirement may not be met during a system's life cycle (International Council on Systems Engineering [INCOSE], 2004). For a government acquisition, this could be understood as a program's failure to achieve one or more of the threshold requirements. Cost risk is the possibility that the specific budget allocated to a program will be exceeded (Blanchard & Fabrycky, 2006; INCOSE, 2004). Schedule risk is the possibility that a program will fail to meet scheduled milestones, and programmatic risk is the external risk posed by the program's environment (INCOSE, 2004). Common causes for program cancellation are cost overruns, schedule slips, and failure to eliminate technological risk. Figure 5 depicts relationships between these risks, as proposed by the INCOSE.

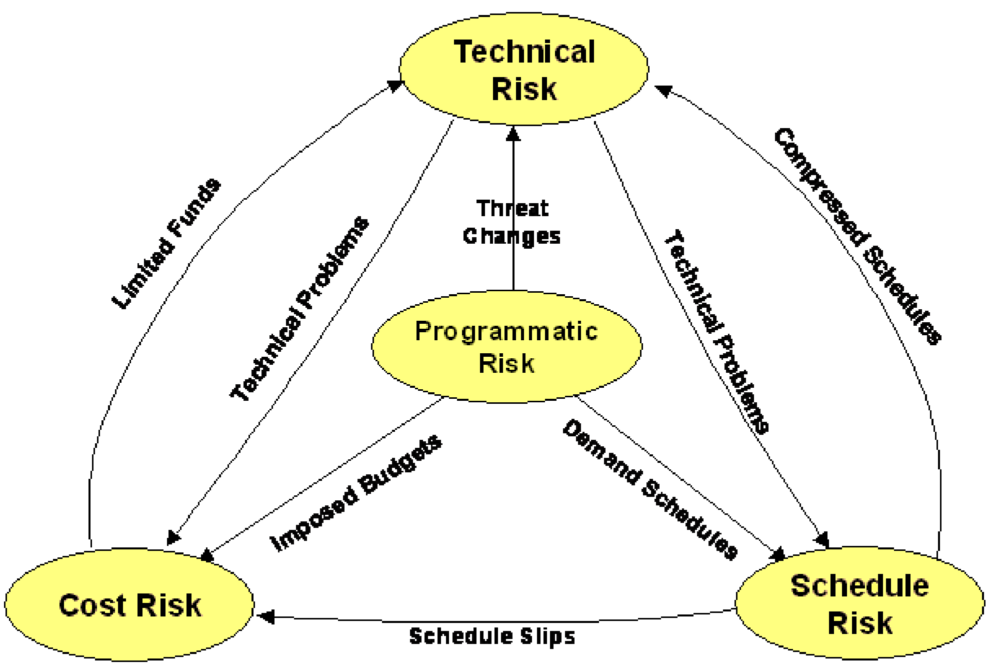


**Figure 5. Typical Relationships Among the Risk Categories**
(INCOSE, 2004, p. 65)

Technical risk is typically highest at the beginning of a program, when a program's technical problems are least understood (INCOSE, 2004). Cost risk also typically decreases as requirements become more defined and as a program gains institutional support. This increase in support protects maturing programs from budget reductions. Schedule risk also normally decreases as a program develops, although the effect of a schedule slip increases as more resources are devoted to a program. FAR (2011) subpart 16.104(d) recognizes that acquisition risk is highest at the beginning of a program:

> Complex requirements, particularly those unique to the Government, usually result in greater risk assumption by the Government. This is especially true for complex research and development contracts, when performance uncertainties or the likelihood of changes make it difficult to estimate performance costs in advance.

### 3. ACQUISITION PHASE AND PREFERRED CONTRACT TYPE

As a program progresses through the acquisition life cycle process, risk typically decreases. During the concept refinement and technical development phases, risk is high. Critical technologies that are projected to mature may not (INCOSE, 2004), and newer programs may be more susceptible to "paying the bills" of another program (Software Engineering Institute [SEI], 2009). Approval to proceed from one acquisition phase to another comes from the MDA, as we explain in Chapter III. Figure 6 illustrates the typical contract type utilized in the acquisition process by life cycle phase.

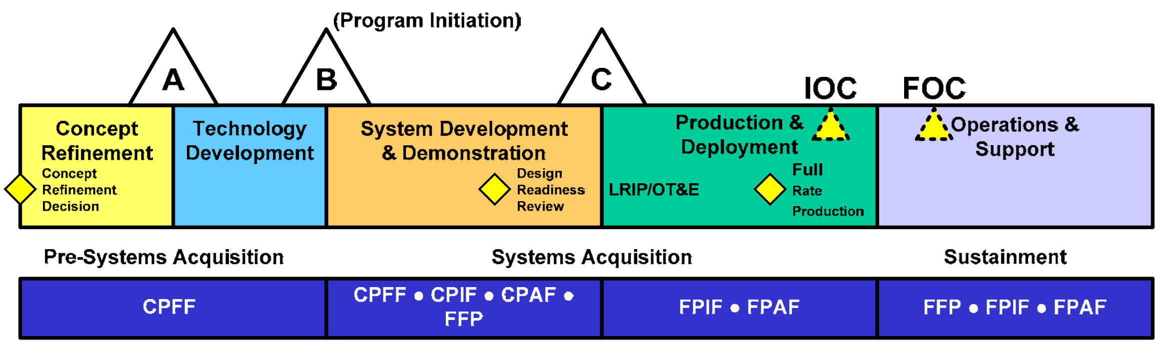


**Figure 6. Contract Type by Life Cycle Phase**
(DAU, 2008)

Developmental work typically requires cost-reimbursement contracts (FAR, 2011). During the concept refinement and technology development phases, the

predominant contract type is CPFF (DAU, 2008). This is in keeping with the higher risk associated with contract performance during those phases, although CPFF is not the only contract type used before MS B. R&D continues during the EMD phase, but by this point programs typically demonstrate enough technical maturity and design stability to permit contract types with less government cost risk. CPFF, CPAF, CPIF, and FFP contracts are common during the EMD phase (DAU, 2008), along with FPIF contracts, which we examine in Chapter V. The FAR (2011) recommends that when follow-on production requirements have been contemplated for an R&D contract, contracts should progress from cost reimbursement to fixed price. System acquisition contracts during the production and deployment phase tend to be FPIF or FPAF, and sustainment contracts are often FPIF, FPAF, or FFP.

Preferred contract types shift based on changing policy guidance, phase, or research. A study (Sadeh, Dvir, & Shenhar, 2000) in Israel on 110 defense development projects found that cost-plus-incentive-fee contracts resulted in better performance when technological uncertainty was high at the start of the project. The study recommended a combination of cost-plus and fixed-price contracts for projects, moving toward fixed price when uncertainty is reduced (Sadeh et al., 2000). Debate continues as to when uncertainty is reasonably low enough to regularly permit fixed-price contracts. A current DoD proposed rule would increase the use of FPIF contracts during EMD for the purpose of attaining better contract performance (Levin, J., 2011). In later chapters of this research report, we examine the relative performance of contracts during production years on the basis of predominant contract type during EMD, with the intent of solving the debate regarding the merit of various contract types during EMD.

Because the contracting officer is responsible for safeguarding the interests of the government (FAR, 2011, subpart 1.602-2), the ultimate responsibility to appropriately select a program's contract type rests with him or her. The FAR (2011) states that, "selecting the contract type is generally a matter for negotiation and requires the exercise of sound judgment" (subpart 16.103(a)). With the exception of stating that the contracting officer is responsible for determining the contract type through negotiation with contractors, the FAR is largely silent on who else should be involved in the decision,

with the exception of R&D contracts. In practice, determining a program's contract type is often a collaborative decision between a program's contracting officer and program manager or contract user representative. This collaborative approach is recommended to contracting officers for R&D acquisitions in the FAR (2011) due to "the importance of technical considerations in R&D" (subpart 35.006(b)). DFARS (2011) subpart 234.004(2) goes further and dictates that an MDAP's MDA should select the development program contract type, taking into consideration the contracting officer's recommendation, at the time of MS B approval. This DFARS exception to the typical practice of the contracting officer selecting the contract type reinforces the collaborative nature of determining contract type.

The FAR (2011) provides "a wide selection of contract types … in order to provide needed flexibility in acquiring the large variety and volume of supplies and services required by [the government]" (subpart 16.101). The flexibility given to contracting officers in determining contract types and the collaboration suggested in making the determination of contract type indicates the complex nature of selecting a contract type, regardless of the acquisition phase. Accordingly, no particular contract type is the universal answer for any acquisition phase.

## E. IMPORTANCE OF RESEARCH AND DEVELOPMENT

Four main causes of program failure have been identified in other research, including requirements changes, budget instability, technology risk, and poor execution due to inadequate program decision-making information (Miller, 2008). R&D reduces technology risk for system acquisition programs and is, thus, critical to program success both during and after the main acquisition phases associated with R&D, which are as follows: concept refinement, technology development, and system development and demonstration. Two areas that contribute to the relative success of programs during and after the R&D acquisition phases are R&D contracting and technology readiness.

### 1. R&D CONTRACTING

Program managers must use careful consideration when determining the type of contract used for R&D efforts. R&D contracts should encourage high creativity and

innovation. The FAR (2011) states that "the primary purpose of contracted R&D programs is to advance scientific and technical knowledge and apply that knowledge to the extent necessary in order to achieve agency and national goals" (subpart 35.002). Contracting officers must judiciously apply the FAR policies on contract type to achieve the government's purpose for R&D efforts. MDAPs are only responsible for a portion of R&D spending within the DoD. Much of this non-MDAP spending is devoted to basic research, including technology exploration that takes place long before technologies mature to the point necessary to begin MDAPs. The primary purpose of MDAP R&D contracting is to improve the technology readiness of a system's contemplated critical technologies through developmental and applied research.

One of the imperatives of R&D contracting is to establish a full understanding between the parties regarding the intent of the R&D effort (FAR, 2011). This understanding can be impaired due to misunderstanding on the part of either party to the contract, resulting in R&D efforts that do not meet the needs of the government. Due to the uncertainty and ambiguity present in R&D efforts, the FAR (2011) instructs contracting officers to avoid sealed bidding. Contracting officers should instead utilize competitive negotiations with offerors to establish a comprehensive mutual understanding of the project (FAR, 2011).

Providing flexibility with minimal administrative burden should be considered by contracting officers (FAR, 2011), but clear objectives must be conveyed for program success. Contracting officers should utilize technical personnel to define clear objectives for R&D projects (FAR, 2011). The DoD Space-Based Infrared System (SBIRS) is an example of negative results due to unclear objectives. The GAO (2003) reported that the cost overruns and schedule delays for SBIRS began at the inception of the program due to immature technologies and unclear requirements. In keeping with the FAR (2011), it is critical to successful developmental and applied research to encourage contractors to "exercise innovation and creativity" in responding to "clear and complete … end objectives" (subpart 35.005). A well-defined research objective, combined with a clear understanding between the government and contractor, contributes to the relative success of a program by removing a potential impediment to MDAP R&D success.

### 2. TECHNOLOGY READINESS LEVELS

The level of uncertainty during R&D varies greatly, particularly during the early phases of a program. Improved technology readiness is theorized to contribute to the success of MDAPs during and after the R&D acquisition phases. Some researchers suggest that the relative maturity of an MDAP's technologies contributes to improved cost and schedule variance outcomes.

Some programs begin R&D with more mature technologies, but others have immature technologies. Program technologies must advance to certain minimum levels before programs are permitted to move beyond the technology development and EMD phases (DoD, 2011). Making consistent, informed judgments regarding the maturity of an MDAP's technology requires a uniform system of measurement. One method of defining the maturity of a program's technology is using technology readiness levels (TRLs) to rate the readiness of a technology against set criteria. Table 1 includes a summary of the TRL descriptions as shown in section 10.5.2 of the *Defense Acquisition Guidebook* (DoD, 2011).

**Table 1. TRL Descriptions**
(DoD, 2011)

| Technology Readiness Level | Description |
|---|---|
| 1. Basic principles observed and reported. | Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties. |
| 2. Technology concept and/or application formulated. | Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies. |
| 3. Analytical and experimental critical function and/or characteristic proof of concept. | Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. |
| 4. Component and/or breadboard validation in laboratory environment. | Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory. |
| 5. Component and/or breadboard validation in relevant environment. | Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components. |

| | |
|---|---|
| 6. System/subsystem model or prototype demonstration in a relevant environment. | Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. |
| 7. System prototype demonstration in an operational environment. | Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft. |
| 8. Actual system completed and qualified through test and demonstration. | Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications. |
| 9. Actual system proven through successful mission operations. | Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions. |

The use of TRLs is credited with enabling "consistent, uniform, discussions of technical maturity across different types of technologies" (DoD, 2011, p. 853). TRLs are limited, however, to maturity and do not directly address the probability that a part or subsystem will achieve the maturity required for system production. TRLs are also assessed on an ordinal scale, so it is incorrect to assume that a system will require equivalent effort to increase from one level to the next. Current DoD policy requires MDAPs to achieve TRL 6 by MS B and TRL 7 by MS C (DoD, 2011). The *Defense Acquisition Guidebook* (DoD, 2011) also instructs MDAs to "consider the recommended TRLs … when assessing program risk." However, TRLs should not be the sole measure of a program's technical risk because they do not measure the potential impact of failing to achieve technology maturity. TRLs cannot offer a full assessment of program risk, but they do provide decision-makers with uniform, comprehensible data regarding a program's present technology maturity.

Miller (2008) blamed requirements changes, technology risk, and poor execution due to insufficient or improper program decision-making information as three of the causes of poor performance for MDAPs. Programs entering the technology development phase with higher minimum and average TRLs have been shown to exhibit lower cost growth and schedule growth (Dillard & Ford, 2009). Higher levels of technology readiness could operate in an inverse relationship to technology risk: an MDAP with

increased TRLs relative to its acquisition phase would then exhibit lower technology risk. Increasing the impartial use of TRLs could also improve program decision-making (GAO, 1999). It is therefore possible that higher TRLs relative to an MDAP's acquisition phase could possibly mitigate Miller's (2008) causes of poor performance.

Improved technology readiness contributes to the success of programs during and after the R&D acquisition phase. Recent evolutionary acquisition efforts within the DoD have focused on using more mature technologies to develop incremental capabilities. Some researchers suggest that programs with higher TRLs tend to exhibit better cost and schedule performance (Dillard & Ford, 2009). Differences in TRLs may explain some of the variation not otherwise explained by the variables we model in later chapters.

## F. SELECTED ACQUISTION REPORTS

Selected Acquisition Reports (SARs), which are published annually, are one of the main sources of data we used for the analysis in this study. These reports provide a snapshot in time for each program we analyzed. As mandated by Congress under 10 U.S.C. §2432 (2011), the Secretary of Defense must submit SARs for all MDAPs or programs designated as high interest by the USD(AT&L). Congress utilizes these reports to track the progress of MDAPs, specifically to detect early warnings of cost or schedule overruns (DoD, 2011).

SARs summarize the latest status of total program cost, schedule, and performance as well as program unit cost and unit cost breach information. Each SAR provides a full life cycle cost analysis for the reporting program and is prepared annually in conjunction with submission of the president's budget. Subsequent quarterly exception reports are required only for those programs experiencing unit cost increases of 15% or more, or schedule delays of six months or greater since the current estimate reported in the previous SAR, or when MS B or MS C approval occurs within the reportable quarter (DoD, 2011).

## G. DEFENSE ACQUISITION EXECUTIVE SUMMARIES

Defense Acquisition Executive Summary (DAES) reports are published quarterly and are the other source of data for the analysis we conducted in this research. DAES reports provide a comprehensive summary of ACAT I and ACAT 1A programs between milestone decision points. The DAES reports must contain program assessments, unit costs, current estimates of program baselines, and the status of exit criteria. They present the projected total costs and quantities for all remaining years of an acquisition program's life. DAES information is designed to provide indications of both potential and actual program problems to the USD(AT&L) and to the Assistant Secretary of Defense (Networks & Information Integration) before they become significant. The reports provide action taken or planned to mitigate future program problems (DoD, 2011).

## H. SUMMARY

In this chapter, we summarized the background information required to understand the scope of this research. We presented the three support systems that form the DoD's acquisition system, and we briefly explained the federal contract types applicable to commercial acquisitions and the preferred contract types for each DoD acquisition phase. We concluded the chapter with the importance of R&D to acquisition program success and discussed the primary documents from which this study draws.

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# III. PURPOSE

## A. OVERVIEW

The purpose of this research is to better understand indicators of program and contract cost variances. Establishing accurate cost information prior to entering the EMD and production phases is extremely important to ensuring a successful program (Carter, 2011). We propose that preproduction and contract-level variances, including those reported during the EMD phase, are one possible set of indicators of future program cost variances. Interpreting these variances requires an understanding of the reasoning behind them and of their methods of construction.

In this chapter, we provide the information required to understand program- and contract-level variances, including program cost, schedule, and engineering variances, as well as contract earned value cost and schedule variances. Previous research has been performed on cost overruns by contract type (Berteau et al., 2011), and recent initiatives have recommended the increased use of fixed-price contracts (Carter, 2010). One purpose of this research is to identify the effect of fixed-price contracts on program variances.

In this chapter, we explain the regulations that govern these variances and that inform the decision-making of acquisition professionals. We also define each of the program and contract variances referenced in this research. We conclude the chapter with an explanation of why the study of these acquisition variances is important.

## B. ACQUISITION OVERSIGHT

The defense acquisition process includes extensive program oversight and data reporting requirements. Program oversight has not produced the desired effect—capable systems delivered on time and within budget. However, a closer review of the program and contract variance data collected under present reporting requirements may reveal novel conclusions about the interdependent nature of the problems associated with defense acquisition.

The current system of acquisition oversight is the result of numerous reforms (Rothenflue & Kwolek, 2010). In the following sections, we discuss some of these reforms, including the Nunn-McCurdy Amendment and several other influential reforms, which substantially contributed to the structure and content of the variance data analyzed in this research.

### 1. The Nunn-McCurdy Amendment

One reform that significantly changed oversight procedures and focused on controlling cost growth was the Nunn-McCurdy Amendment. Nunn-McCurdy, first introduced in the Department of Defense Authorization Act of 1982, expanded the SAR requirements established in 1969 (Rothenflue & Kwolek, 2010). Nunn-McCurdy required program managers to submit SARs to Congress annually or immediately following a growth of 15% over the total program acquisition unit cost (PAUC) and average procurement unit cost (APUC). Nunn-McCurdy is still a public law, so program managers are still required to submit SARs. SARs must include any change in schedule milestones and system performance (Department of Defense Authorization Act, 1982). Additional reporting guidance has been added to the Nunn-McCurdy statute over the years and that guidance remains today as a control method for holding program managers accountable for cost growth on MDAPs.

The most recent changes to the statute occurred in 2006 and 2009. The National Defense Authorization Act for Fiscal Year 2006 amended Nunn-McCurdy to include significant and critical dollar amount thresholds rather than a single threshold (GAO, 2011a). In the act, significant cost growth is defined as a 15% increase to the current baseline or a 30% increase to the original baseline for the PAUC or the APUC.[1] Significant cost growth requires congressional reporting. Critical cost growth is defined as a 25% increase to the current baseline estimate or a 50% increase over the original baseline estimate for the PAUC or APUC (GAO, 2011a).

[1] PAUC = (Total Development $ + Procurement $ + Construction $)/Total Program Quantity. APUC = Total Procurement $/Procurement Quantity.

It is important to understand estimates and baselines when discussing the Nunn-McCurdy Amendment. The current baseline estimate is defined as the latest estimate on an approved program, defined as the currently approved acquisition program baseline (APB). The original baseline estimate is defined as the APB approved at MS B or program initiation, whichever occurs later (Axtell & Irby, 2007). Each military Service must establish a baseline for each of its MDAPs, including parameters to describe the cost estimate (referred to as the baseline estimate), schedule estimate, performance estimate, and any other important factors of an MDAP (10 U.S.C. § 2435, 2011). According to 10 U.S.C. § 2435 (2011), the revision of the original baseline should be changed to the new baseline only after a critical (Nunn-McCurdy) breach; if this happens, the Secretary of Defense notifies Congress of the breach in the next SAR and gives reasons for the adjustment or revision (10 U.S.C. § 2435, 2011).

The Weapon Systems Acquisition Reform Act (WSARA) of 2009 added further repercussions for programs with critical cost growth. Among other requirements, WSARA added the presumption that a program will be cancelled unless the Secretary of Defense "certifies (with reasons and supporting documentation) that continuing the program is essential to national security and that the program can be modified to proceed in a cost-effective manner" (Lymon, McWhorter, & Violette, 2011, p. 20). Critical cost growth also requires the program to "receive a new milestone approval (and associated certification) prior to the award of any new contract or contract modification extending the scope of the program" (Lymon et al., 2011, p. 20).

WSARA also requires departments to perform an independent cost estimate supporting a program's cost reasonableness and a stated confidence level for that estimate (Levin, C., 2009). The requirement for a stated confidence level echoes an observation made by the GAO (2008) in a report to the Senate Armed Service Committee: "To make more informed investment decisions, cost estimating best practices call for estimating a range of possible costs around a point estimate to provide information about the levels of uncertainty and confidence" (p. 24). There were seven Nunn-McCurdy breaches in 2010

to the APBs—four significant and three critical (USD[AT&L], 2011). In the following section, we explain APBs, the initial program baselines that Nunn-McCurdy breaches were based on.

### 2. Acquisition Program Baseline

The APB was established by the Defense Acquisition Improvement Act of 1986 to create a baseline to improve program stability. The APB is defined by the DAU as the "baseline that reflects the threshold and objective values for the minimum number of cost, schedule, and performance attributes (called 'key performance parameters') that describe the program over its life cycle" ("Acquisition Program Baseline," 2009). The APB answers how the system is supposed to perform when critical events occur, and how much the program should cost. Every program manager must submit and receive approval for program goals prior to initiation of all acquisitions (USD[AT&L], 2008). The APB satisfies the requirement for goals on all ACAT I programs.

By tracking actual program performance against established baselines, the program manager is alerted to potential problems and can take early corrective action. If a program breaches an approved baseline threshold, the program manager must submit a formal memo to the MDA and to the component's leadership. A breach of performance is defined as a failure to meet the specific parameter's threshold value as laid out in the APB. A breach of schedule is failure to meet the objective date plus six months. A cumulative program cost increase of 10% or greater from the approved cost baseline is a cost breach ("Acquisition Program Baseline," 2009).

### 3. Selected Acquisition Reports

SAR requirements are covered under 10 U.S.C. § 2432 (2011). SAR submittal is required annually on December 31 unless a significant or critical cost growth occurred or a delay of six months in any current estimated milestone occurs, both of which require a quarterly report (10 U.S.C. § 2432, 2011). SARs contain the following 19 sections:

1. Program Identification,
2. Program Information,

3. Responsible Office,
4. References,
5. Mission and Description,
6. Executive Summary,
7. Threshold Breaches,
8. Schedule,
9. Performance,
10. Track to Budget,
11. Cost and Funding,
12. Low-Rate Initial Production,
13. Nuclear Cost,
14. Foreign Military Sales,
15. Unit Cost,
16. Cost Variance,
17. Contracts,
18. Deliveries and Expenditures, and
19. Operating and Support Cost.

Section 16, Cost Variance, is reported in a SAR in the following four steps. In the first step, the total variance for each program's appropriations estimate is calculated. Second, the category for the particular change is identified. Third, the dollar amount for each variance category by FY is determined. Finally, a clear and understandable explanation for the changes is provided (DoD, 2010).

A program's total CV comes from many different sources. These are aggregated in SARs into seven categories. In later chapters of this research report, we describe the relationships deduced from SAR CV data and other data. Accordingly, it is important to understand the categories comprising the program's total CV, which are shown in Figure 7.

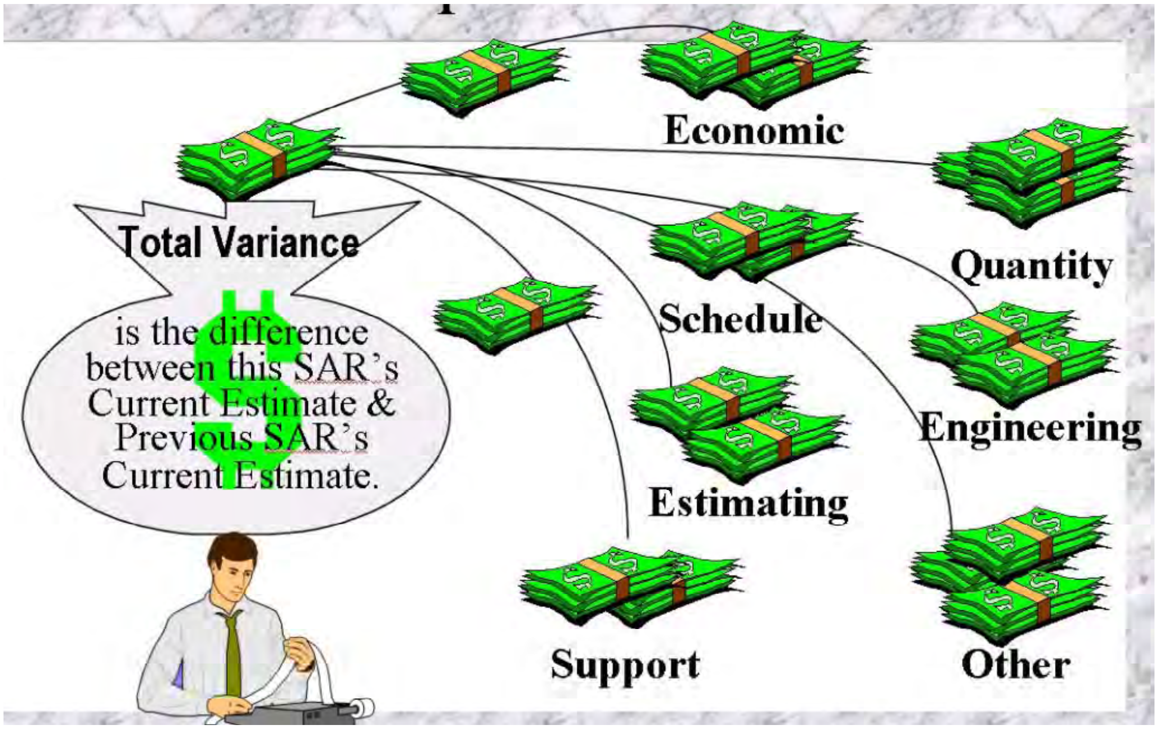


**Figure 7. Total Program Variance Factors**
(DoD, 2010)

The various cost variances are calculated for the SARs, which are uploaded to DAMIRS. The variance that occurred between reports for each factor in Figure 7 must be verbally explained in the SAR.

According to a GAO (2011a) study, engineering and design issues, schedule issues, and quantity changes were the primary reasons cited for unit cost growth that led to Nunn-McCurdy breaches. In a study performed by David McNicol (2004) on cost growth, he identified three areas that caused growth in procurement costs: increased system capabilities, an unrealistic estimate of cost growth, and poor program execution or exceptional budget instability. In this research, we focus on CV, SV, and EV as potential leading indicators of relative program success or failure since the other primary reason—quantity change—is more likely to be a lagging rather than leading indicator (Gansler, 2010).

### 4. Earned Value Management

Former USD(AT&L) Dr. Jack Gansler signed a memorandum in August 1999 announcing the DoD's adoption of the Earned Value Management (EVM) system (Office of the Secretary of Defense, 2002). EVM is a mandatory reporting requirement for cost and incentive contracts valued at $20 million or greater, to include all MDAPs, and is governed by DFARS (2011) subpart 234.2 and DoD Instruction 5000.02 (USD[AT&L], 2008). The use of EVM is optional for the program manager on any contract valued at less than $20 million based on a cost-benefit analysis (USD[AT&L], 2008).

EVM is a tool used to manage programs that attempts to integrate contract cost, schedule, and technical parameters in order to hold all parties accountable for large, complex acquisitions. Program managers are ultimately accountable for confirming that EVM requirements are included in statements of work, and program managers can utilize the variance measurements to forecast contract cost and schedule performance. The program manager can use EVM to track the status of the contracts within his or her program and use the measurements from EVM to build corrective action plans to get the program back on track.

Problems with individual contracts may impede the progress of a portion of a program, or they may cause cascading problems across multiple contracts within a program and the program as a whole. In later chapters, we examine contract cost and schedule variances as determinants of relative program success. In the following section, we explain the main SAR output of EVM, contract cost and schedule variances, in greater detail. For the sake of clarity, in this research we avoid referring to earned value as "EV" in order to better distinguish earned value from engineering cost variance (EV), which we define later in this section.

## C. CONTRACT VARIANCES

Two main EVM metrics—cost variance and schedule variance— are reported for every active MDAP contract, meaning every MDAP contract that is less than 90% complete. Multiple cost and schedule contract variances are routinely reported on a

single program SAR.  To better understand contract cost variance and schedule variance, we further define these terms in the next sections.

### 1. Contract Cost Variance

Contract cost variance is a metric that calculates cost performance by subtracting the actual cost of work performed (ACWP) from the budgeted cost of work performed (BCWP).  The value is at a particular point of time and shows cumulative cost variance to date.  A positive value is favorable because it indicates the work was performed under budget.  A negative value is unfavorable because it indicates more money was spent than was budgeted for the task.

Contracts experiencing unfavorable cost variance are likely to experience a contract cost overrun because it is difficult to reduce budgeted future work unless quantities or scope of work are reduced ("Cost Variance," 2009).  SAR contract cost variances are reported as the change in BCWP minus ACWP rather than in current-year or base-year dollars.  For the sake of clarity, in this research we avoid abbreviating contract cost variance as "CV" in order to better distinguish contract cost variance from program cost variance (CV), which we define later in this section.

### 2. Contract Schedule Variance

Contract schedule variance is a metric that calculates schedule performance by subtracting the budgeted cost of work scheduled (BCWS) from the BCWP.  The value is expressed for a specific period of time or is cumulative to date.  A positive value is favorable because it indicates more work than scheduled has been completed.  A negative value is unfavorable because it indicates that planned work was not completed.  Both a slip in schedule and a failure to achieve certain technical milestones as planned can result in a negative schedule variance.

Programs experiencing unfavorable schedule variance may also experience a delayed completion, but they can possibly recover in the future ("Schedule Variance," 2009).  For the sake of clarity, in this research we avoid abbreviating contract schedule

variance as "SV" in order to better distinguish contract schedule variance from program schedule variance (SV), which we define later in this section.

## D. PROGRAM VARIANCES

Over the last 20 years, the Army cancelled 22 major programs before they entered production; the costs already incurred were approximately $1 billion in 1996 and reached a high of $3.8 billion per year after 2004 (Ewing, 2011). Common causes for program cancellation are cost overruns, schedule slips, and underestimation or failure to eliminate technological risk. In our research, we examine at the program level three corresponding categories of variance (cost, schedule, and engineering variance) found in the SARs. To better understand the difference between these program variances, we further define them in the next sections.

### 1. Cost Variance

Program cost variance (CV) is reported in two general forms: as the cost change between the program's current SAR and previous SAR, which is the indicator we employ. In addition the cost change between the program's current SAR and SAR baseline is also reported. A positive value is unfavorable because it indicates that the estimated cost of the program has increased. A negative value is favorable because it indicates that the estimated cost of the program has decreased. Changes in CV are subdivided in seven categories: economic, quantity, schedule, engineering, estimating, other, and support. The variances associated with these seven categories sum to the cost variance. We examine two of these categories, schedule and engineering, more closely in the following sections.

### 2. Schedule Variance

Schedule variance (SV) is cost variance attributable to schedule changes. SV is a component of CV. Since SV is a component of CV, the two will covary. Accordingly, the CV we used in this research provides explicit explanatory information about the subcomponents SV and EV.

### 3. Engineering Variance

Engineering variance (EV) is cost variance attributable to engineering changes and is a component of program cost variance. EV is more difficult to quantify than SV and is referred to in DoD contracting offices as the cost of an approved engineering change proposal. This variance occurs due to new technology upgrades, redesign, and configuration changes. As with all SAR cost variance categories, a descriptive explanation is provided in the SAR to aid understanding of what caused the variance. Changes in support items are not included in EV (DoD, 2010).

Engineering changes typically occur to a specific item identified on the work breakdown structure (WBS). A WBS defines the deliverable element by the scope of work. If the scope changes, an engineering variance to total cost will likely occur. Minimizing changes and beginning a program with a clear and well-defined requirement is the best prevention for poor engineering variance performance (GAO, 2011).

Because engineering cost variance is a component of total program cost variance, the presence of any engineering cost variance will cause the two to display covariance. As a result, when we discuss CV, it encompasses SV and EV. Because of this, when conducting much of the analysis on the models we developed in this paper, we subtracted SV and EV from CV. We call this Program Net Cost Variance later in the analysis.

## E. REASONS TO STUDY

Understanding what variables affect program costs and CVs, and the linkages between contract and program data, is the purpose of this research. To better understand possible drivers of program CVs, we examine the historical effects of preproduction decisions on production CV outcomes. Improving program cost outcomes has been the subject of many acquisition reforms, but these reforms have not addressed the complexity and interdependence found in DoD acquisition programs that drive poor program cost, schedule, and technical outcomes (Rothenflue & Kwolek, 2010).

We examine several potential cost variance drivers in later chapters, including contract type during the EMD acquisition phase, program and contract variances, and

MDAP type. It would be beneficial to the acquisition workforce to better understand each of these potential causes of variance.

### 1. R&D's Effect on Life Cycle Costs

R&D contracts for FY2010 totaled $80 billion (USD Comptroller, 2011). Increasing the number of R&D contracts issued on a fixed-price incentive basis could yield significant savings based on the presumption that fixed-price incentive contracts decrease cost overruns (Kendall, 2011). At one time, the DoD attempted to impose fixed-price incentive contracts on efforts in which significant invention could be anticipated, although recently the use of cost-plus-award-fee contracts has become widespread (Carter, 2010; Darst & Roberts, 2010). Under Secretary Carter (2010) has advocated the use of fixed-price incentive firm target contracts in the place of cost-plus-award-fee contracts wherever practicable, including EMD contracts which are of particular interest to policy-makers (Carter, 2011).

The changing political favorability of particular contract types must be evaluated with the regulations implicit in the 13 federal contract types listed in FAR (2011) part 16; different contract types are better suited to different types of work. This truth is consistent with the discretion given to the acquisition team in FAR (2011) subpart 1.102 to "use sound business judgment." The contract types most significant to MDAPs were discussed in Chapter II.

Program managers and contracting officers should understand that the selection of an inappropriate contract type during EMD can negatively impact contract performance (Sadeh et al., 2000). Restricting R&D work to a fixed-price incentive basis could negatively affect problem detection and problem solving early in a program if the risk conditions are such that a fixed-price contract type is not appropriate. Contracted companies could avoid researching all problems and alternative program solutions in order to increase their profit margin on the fixed-price contracts, provided that the contract specification requirements are satisfied. Poor problem detection early in a program will likely increase program costs in the long-term. Good EMD contract performance and appropriate problem solving can address potential technical and system

integration issues before production, when they are most costly to address. Studying the effect of EMD contract type may give important insight into the wisdom of incentivizing program managers to select more restrictive contract types.

### 2. Aid Current Practitioners' Programmatic Decision-Making

Examining potential sources of variance may improve program managers' understanding of reasons for the relative success of programs. A better understanding of these reasons could aid the decision-making of current practitioners. Preproduction program cost, schedule, and engineering variance, and current period contract earned value cost and schedule variance are proposed by acquisition managers as possible indicators of future program cost variances. CV, SV, and EV within individual programs have been qualitatively linked and, to an extent, quantitatively linked (Rothenflue & Kwolek, 2010). Further study is necessary to better determine the nature of the interdependence between these program and contract variances. An improved understanding of this interdependence could enhance practitioners' ability to estimate a contract's most likely final cost, a program's schedule or cost variances, or a program's relative cost risk, given past program and contract variances.

Other factors are proposed by acquisition managers as possible reasons for program cost variances, including MDAP segment. An MDAP segment is the acquisition portfolio segment that a program falls into, such as aircraft, missiles, ammunition, shipbuilding, or other, as defined by the categories listed in the *National Defense Budget Estimates for FY2012* (USD Comptroller, 2011). In this research, we do not further differentiate between these categories, although such differentiations can be found in the Air Force's *Appropriation Symbols and Budget Codes (Fiscal Year 2012*; Department of the Air Force, 2011), in order to permit program comparisons between similar programs across Services. Some studies of cost and schedule variances have been restricted to a particular MDAP segment, such as aircraft (Rothenflue & Kwolek, 2010); such studies inherently exclude the possible effects of the MDAP segment. Constraining a study to a particular contract type or MDAP segment can control for effects associated with details of that specific type of contract. Although it is unlikely that policy-makers would

develop fewer programs of a given MDAP segment simply due to the relative success of that type of program, examining the relative success of the various MDAP categories in conjunction with other factors could improve acquisition professionals' understanding of the relative risk present in each MDAP segment.

Improving practitioners' understanding of the risks present in MDAPs based on past program performance may enhance future program outcomes by aiding cost estimating and improving program risk assessment. Such developments could improve program outcomes by reducing funding volatility due to cost overruns and could decrease technical risk by improving risk assessment. Other improvements are possible, including program improvements driven by further reform of the acquisition system such as setting shorter program timelines, promoting real competition, and increasing the use of fixed-price incentive contracts (Carter, 2010).

### 3. Recommended Future R&D Management Reforms

A better understanding of cost and schedule variances could identify areas of current policy that would benefit from reform. Novel findings regarding any of the researched causes of program variances could yield potential reform improvements. Conversely, research conducted on the effects of acquisition reforms on defense programs could provide direction for creating more effective policies (Searle, 1997).

Relating the efficacy of past reforms through a review of various yearly effects on variances over time could permit a qualitative review of past reform. Two such studies (Christensen, Searle, & Vickery, 1999; Drezner, Jarvaise, Hess, Hough, & Norton, 1993) showed that program reform initiatives did not improve program performance and, in fact, cost growth worsened after initiatives were implemented. It could be useful to question the conventional thinking that past reforms, such as the Federal Acquisition Streamlining Act (FASA) of 1994, have had a negligible effect on MDAP outcomes (Smirnoff & Hicks, 2008). The most recent acquisition reforms, such as WSARA, have generally focused on reducing risk. It is possible that such reforms may already be improving the acquisition process.

## F. SUMMARY

The purpose of this research is to better understand the determinants of program and contract cost and cost variances. Each possible cause of program variance discussed in this chapter is worthy of further research in order to understand the possible causes of program cost variances. The various program cost variances and contract variances we discussed in this chapter can be qualitatively linked to cost, schedule, and technical performance. We explore these interdependent variables and other possible causes of variance quantitatively in Chapter IV.

# IV. DATABASE CONSTRUCTION AND ANALYSIS

## A. OVERVIEW

In this chapter, we provide an overview of the data we used to analyze the effect of program and contract variances, program segment, contract type, and other variables on program and contract cost during the systems acquisition phase of MDAPs. In this analysis, we seek to close the existing gaps in the understanding of program and contract management data. Cross-referencing contract variances with program variances provides acquisition professionals with a more complete picture of program and contract changes that occur during both the EMD and production phases of the acquisition process.

We first discuss the cross-sectional, time-series data we collected from available resources. The collection of this data permitted us to construct a database containing the numerical and categorical data that we used in the descriptive statistical analysis in this chapter. We provide the descriptive statistics to explore the initial data and to identify initial patterns among programs and contracts. These descriptive statistics enhance readers' understanding of the data we employed in the formal empirical analysis contained in Chapter V, in which exploratory empirical models are estimated.

We then provide a brief overview of cross-sectional, time-series analysis for reader understanding of the models that we estimated. Finally, we present a simple flow diagram depicting the relationships. Our objective was to determine whether the data were consistent so that, in turn, we could determine the effects of contract types and variances on program variances, and if the data were not consistent, based on statistical analysis, we developed an alternative exploratory model. We present this alternative structure and the final conclusions of our analysis in Chapter VI.

## B. DATA COLLECTION

In this research, we used quantitative analysis to answer the research questions. Quantitative studies require that a number of assumptions be made. These include the assumptions that the process used is statistically reliable and operationally meaningful and that legitimate generalizations can be made from the sample to predict, explain, and

understand the population (Creswell, 1994). The method we used was to collect and model our data in the most unbiased manner possible. We also examined normality and other characteristics of the data. In our research, the population was all MDAPs and the sample was the dataset available that fit the required analysis techniques we applied in order to objectively make observations and generalizations about MDAPs.

Our analysis in this study relied on data contained in DAMIRS and FPDS. Because each of the Services use these databases to document acquisition information, the extensive number of SARs provided the most meaningful data. We downloaded each program SAR from DAMIRS and transferred the SAR into Excel, breaking the information in the SARs down by program and contract to allow us to analyze the program and contract variables. When multiple contract line item numbers (CLINs) that are reportable in a SAR were present on a contract, we recorded each one in the database as a separate contract observation, in keeping with the practice used for SARs. We conducted further data collection in FPDS to determine the predominant contract type and obtain data missing in the SARs. Figure 8 shows the number and percentage of the different contract types.

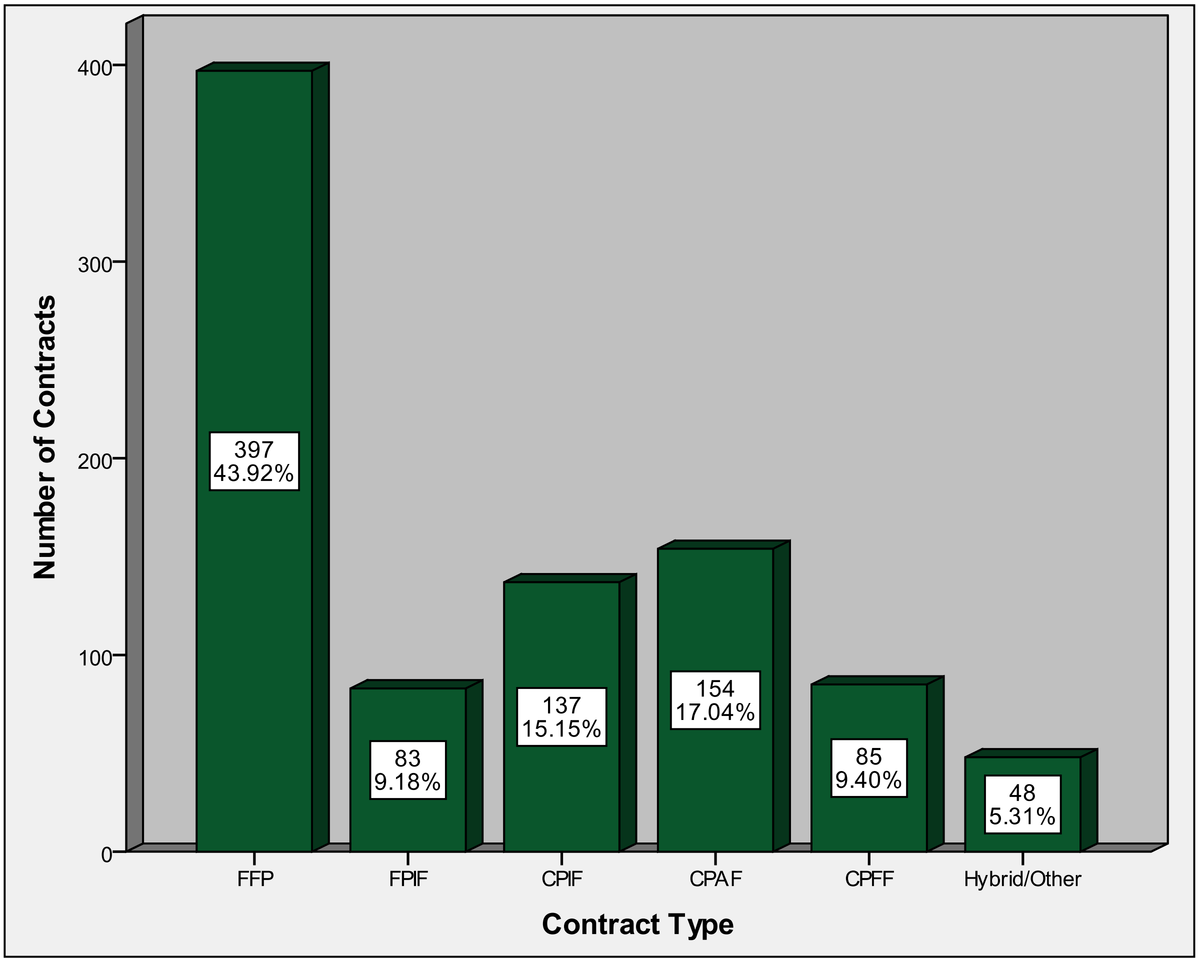


**Figure 8. Actual Contract Type Breakdown**

We grouped contract type into six categories: FFP, FPIF, CPIF, CPAF, CPFF, and Hybrid/Other. The Hybrid/Other category only contained 5% of the contracts and included FPIS, FPEPA, Time and Materials, hybrid contract types with a 50-50 split in contract type, and any indeterminate predominant contract type. A 50-50 split in contract type was found in the database for one contract; since this contract was shown as a perfect split between CPAF and CPIF in the SARs, determining a predominant contract type was not possible. Several indeterminate predominant contract types were also observed; these were most common when a contract had been awarded, but not yet definitized. Some undefinitized contracts in the data could be the result of the program office and contractor still negotiating predominant contract type, particularly in the case of letter contracts.

We also broadly grouped contract type into cost-plus and fixed-price to compare these two categories. The exact number of each contract type for each program can be seen in Table 2, along with the total number of contracts for each program. Table 2 also includes the predominant contract type in EMD, RDT&E, and production. We determined predominant contract type based on the total current contract price for each program. We summed the total, current contract price for each category for the EMD and the production phases, and for RDT&E appropriation contracts. The contract type associated with the largest total, current contract price was designated as the predominant contract type. The EMD predominant contract type variable lacked variability, since no program had a predominant fixed-price orientation during EMD. Due to a lack of variability in predominant contract type during the EMD phase, we extracted the predominant contract type associated with RDT&E appropriations and treated RDT&E as a proxy for EMD, recognizing that using a proxy limited our ability to generalize and draw substantial conclusions from our results. Using a proxy for predominant EMD contract type was thought to be better than not attempting to model predominant EMD contract type at all.

Table 2. MDAP Number of Contracts, Predominant Contract Type During EMD and Production, and RDT&E Appropriation

| | Contract Type | | | | | | | Predominant Contract Type | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Program | CPAF | CPFF | CPIF | FFP | FPIF | Other | Total | EMD | RDT&E | Prod. |
| AB3A | 0 | 0 | 12 | 0 | 0 | 0 | 12 | CPIF | CPIF | CPIF |
| AEHF | 17 | 0 | 0 | 0 | 0 | 0 | 17 | CPAF | CPAF | CPAF |
| AGM-88E AARGM | 0 | 0 | 7 | 2 | 2 | 0 | 11 | CPIF | CPIF | CPIF |
| AIM-9X | 0 | 5 | 6 | 18 | 0 | 0 | 29 | CPIF | CPIF | FFP |
| B-2 RMP | 0 | 0 | 2 | 0 | 2 | 4 | 8 | CPIF | Other | FPIF |
| C-130 AMP | 7 | 0 | 0 | 2 | 0 | 0 | 9 | CPAF | CPAF | FFP |
| C-5 RERP | 3 | 0 | 0 | 6 | 0 | 14 | 23 | CPAF | CPAF | Other |
| CEC | 27 | 6 | 0 | 36 | 1 | 0 | 70 | CPAF | CPAF | CPAF |
| CH-47F | 0 | 9 | 7 | 15 | 7 | 0 | 38 | CPIF | FFP | FFP |
| E-2D AHE | 7 | 0 | 3 | 3 | 4 | 0 | 17 | CPAF | CPAF | CPAF |
| EA-18G | 7 | 4 | 3 | 2 | 3 | 12 | 31 | Other | CPAF | FPIF |
| EXCALIBUR | 0 | 0 | 6 | 8 | 0 | 0 | 14 | Other | CPIF | CPIF |
| F-22 | 13 | 9 | 1 | 47 | 0 | 9 | 79 | CPAF | CPAF | FFP |
| FBCB2 | 8 | 0 | 3 | 8 | 5 | 0 | 24 | None | CPAF | FFP |
| H-1 UPGRADES | 11 | 2 | 0 | 20 | 0 | 0 | 33 | CPAF | CPAF | FFP |
| HIMARS | 0 | 0 | 0 | 25 | 0 | 0 | 25 | None | None | FFP |
| JASSM | 12 | 5 | 6 | 23 | 2 | 0 | 48 | CPFF | CPAF | FFP |
| JDAM | 4 | 0 | 0 | 19 | 0 | 0 | 23 | None | CPAF | FFP |
| JSOW BASELINE | 0 | 0 | 2 | 5 | 3 | 0 | 10 | None | CPIF | FFP |
| LUH | 0 | 0 | 0 | 5 | 0 | 0 | 5 | None | None | FFP |
| MH-60R | 0 | 9 | 15 | 27 | 2 | 4 | 57 | CPFF | CPIF | FFP |
| MH-60S | 0 | 0 | 18 | 29 | 0 | 0 | 47 | None | CPIF | FFP |
| MUOS | 1 | 0 | 6 | 0 | 3 | 1 | 11 | CPIF | CPIF | CPIF |
| NAS | 0 | 0 | 0 | 13 | 0 | 0 | 13 | None | FFP | FFP |
| P-8A | 7 | 0 | 0 | 2 | 0 | 0 | 9 | CPAF | CPAF | CPAF |
| PATRIOT PAC-3 | 0 | 0 | 28 | 23 | 0 | 4 | 55 | CPIF | CPIF | FFP |
| SM-6 | 7 | 0 | 0 | 0 | 1 | 0 | 8 | CPAF | CPAF | CPAF |
| SSN 774 | 2 | 25 | 5 | 0 | 29 | 0 | 61 | None | FPIF | FPIF |
| 1. TACTICAL | 0 | 5 | 0 | 15 | 6 | 0 | 26 | CPFF | CPFF | FFP |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TOMAHAWK | | | | | | | | | | |
| UH-60M | 8 | 4 | 0 | 6 | 0 | 0 | 18 | CPAF | CPAF | FFP |
| V-22 | 13 | 2 | 7 | 38 | 13 | 0 | 73 | None | CPAF | FPIF |
| Total | 154 | 85 | 137 | 397 | 83 | 48 | 904 | | | |

The major program information we extracted from the SARs included the DoD component, the milestones, the projected program, and the variances. The contract information included initial, current, and final price data, and earned value variances. From this collection process, we built an extensive dataset. We developed additional variables to conduct further analysis. We categorized the programs into four segments: (1) Aircraft, including planes and helicopters; (2) Missile, weapons and ammunition; (3) C4ISR, including radar, satellite, and communication systems; and (4) Ship and submarine. Figure 9 shows the breakdown with the number of programs in each segment.

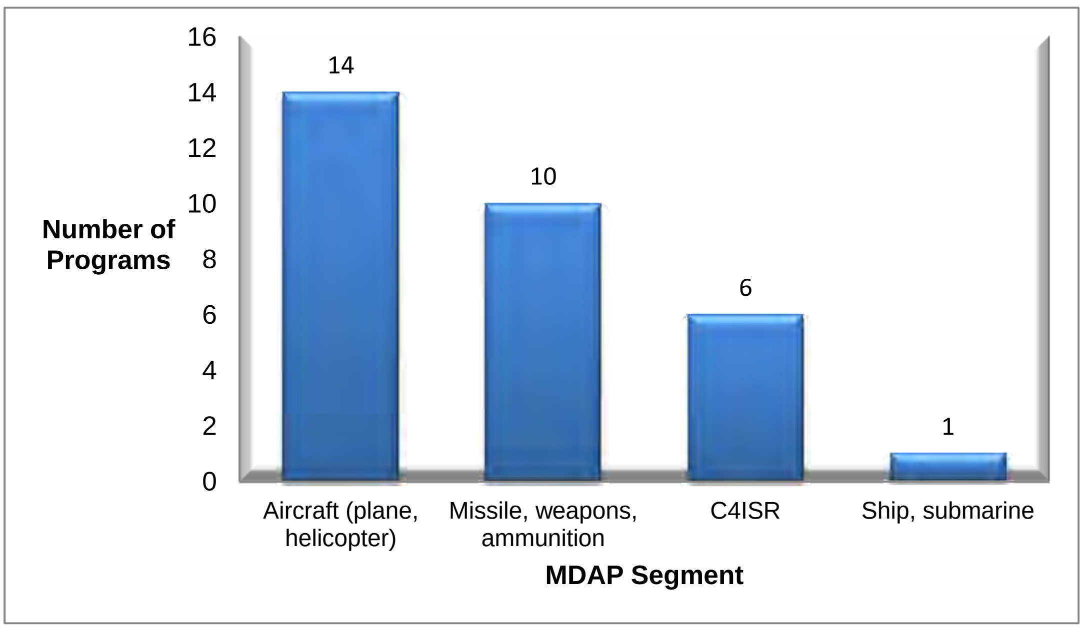


**Figure 9. Number of MDAPs by Segment**

The database consists of cross-sectional, time-series data. The cross section includes multiple programs and their attendant contracts during a particular year. The time series consists of individual programs and their attendant contracts identified by SAR data over a several-year period. A current list of active MDAPs consisted of 84 programs. In order to perform a thorough analysis of the preproduction variance effect

on production, we chose only those MDAPs that included pre- and post-MS B data. To observe the variance effects over time, a minimum of a five-year span in data availability was necessary. This narrowed the number of available programs to 31, listed in Table 3 with their full popular name, branch of service, segment category, and type. The segment codes are: Aircraft = A; Missile, weapons, and ammunition = M; C4ISR = R; and Ship and submarine = S. The program type is either modification (Mod) or new start (New).

### Table 3. Programs Included in the Analysis

| Program | Full Name | Service | Segment | Type |
|---|---|---|---|---|
| AB3A | Longbow Apache—Block IIIA Remanufacture | Army | A | Mod |
| C-130 AMP | C-130 Avionics Modernization Program | Air Force | A | Mod |
| C-5 RERP | C-5 Reliability Enhancement and Reengining Program | Air Force | A | Mod |
| CH-47F | CH-47F Improved Cargo Helicopter | Army | A | Mod |
| E-2D AHE | E-2 Advanced Hawkeye | Navy | A | Mod |
| EA-18G | EA-18G Growler | Navy | A | New |
| F-22 | F-22 Advanced Tactical Fighter | Air Force | A | New |
| H-1 UPGRADES | H-1 UPGRADES (4BW/4BN) | Navy | A | Mod |
| LUH | Light Utility Helicopter | Army | A | New |
| MH-60R | MH-60R Multi-Mission Helicopter | Navy | A | New |
| MH-60S | MH-60S Fleet Combat Support Helicopter | Navy | A | Mod |
| P-8A | P-8A POSEIDON | Navy | A | New |
| UH-60M | UH-60M BLACK HAWK | Army | A | Mod |
| V-22 | V-22 Joint Services Advanced Vertical Lift Aircraft—Osprey | Navy | A | New |
| AGM-88E AARGM | AGM-88E Advanced Anti-Radiation Guide Missile | Navy | M | Mod |
| AIM-9X | AIM-9X Air-to-Air Missile | Navy | M | New |
| EXCALIBUR | Excalibur Precision 155mm Projectiles | Army | M | New |
| HIMARS | High Mobility Artillery Rocket System | Army | M | New |
| JASSM | Joint Air-to-Surface Standoff Missile | Air Force | M | New |
| JDAM | Joint Direct Attack Munition | Air Force | M | New |
| JSOW BASELINE | Joint Standoff Weapon Baseline Variant and Unitary Warhead Variant | Navy | M | New |
| PATRIOT PAC-3 | Patriot Advanced Capability-3 | Army | M | New |
| SM-6 | Standard Missile-6 | Navy | M | New |
| 2. TACTICAL TOMAHAWK | Tactical Tomahawk R/UGM-109E | Navy | M | New |
| AEHF | Advanced Extremely High Frequency Satellite | Air Force | R | New |
| B-2 RMP | B-2 Radar Modernization Program | Air Force | R | Mod |
| CEC | Cooperative Engagement Capability | Navy | R | Ne |

| | | | | |
|---|---|---|---|---|
| | | | | w |
| FBCB2 | Force XXI Battle Command Brigade and Below Program | Army | R | Ne w |
| MUOS | Mobile User Objective System | Navy | R | Ne w |
| NAS | National Airspace System | Air Force | R | Ne w |
| SSN 774 | SSN 774 Virginia Class Submarine | Navy | S | Ne w |

We performed normality tests on the variables in the dataset. There are a number of graphical and non-graphical normality tests. A simple graphical test of normality is a histogram. We graphed a histogram for each dependent variable to determine whether the variance measures were normally distributed. The variance measures that were the primary focus of the research each displayed a bell shape similar to a normal distribution, but with excessive kurtosis that caused the data to be non-normal. The statistical methods used in this research were sufficiently robust to accommodate the use of variables exhibiting non-normality. Further explanation of the non-normality exhibited can be found in Appendix B.

## C. DESCRIPTIVE STATISTICS

The questions we address in this research required quantitative analysis. Typically, the first step undertaken in an empirical analysis is to establish descriptive statistics (Hair, Black, & Anderson, 2009). In this research, we examined two basic data types: nominal data and interval data. Each type of data required a different type of analysis.

Interval data are the least restrictive of these two data types. Also known as scale data, interval data include observations that can be compared numerically. Program cost variances, schedule variances, and engineering variances, and contract cost variances and schedule variances are examples of interval data. The program variances are reported in constant 2010 millions of dollars, and have the same scale. The contract variances are reported in then-year millions of dollars over the course of the contract. Conversion of the contract variances to constant 2010 millions of dollars was not attempted, since measuring the period of performance and the weighted spend rate for observation would have been prohibitively complicated. Some of the most common measures used to

examine interval data include the mean, range, and standard deviation. Statistical techniques valid for nominal data are also frequently used.

Nominal data include observations by category that cannot be placed in a logical order. The type of contract used for an acquisition is an example of nominal data. Although contracts exhibit risk along a scale in a defined order, not all contract types are practical for a given acquisition, so it is not universally valid to generalize that CPFF follows CPAF, which follows CPIF. This precludes the consideration of contracts as ordinal data. Nominal data are examined for mode and frequency of occurrence, and typically are used to construct categorical variables (0-1) for each nominal category. For nominal data, cross-tabulation (crosstab) tables can be a helpful descriptive statistic for comparing the nominal categories of one variable with the categories of other variables. An example of a crosstab table is Table 2, showing the number of contract types for each program.

In this research, we examined data to determine the causes of program and contract cost growth. A critical first step in our statistical analysis was the application of descriptive statistics to the data. We examined nominal and interval data using appropriate statistical techniques.

## D. THEORETICAL FOUNDATION

Following the completion of the first step of applying descriptive statistics, we used several statistical techniques to further examine the cross-sectional, time-series database we developed from DAMIRS. The primary technique we employed was multiple regression analysis. We used multiple regression analysis to model the association between each included explanatory variable and the dependent variable of our cross-sectional, time-series dataset. After conducting initial regressions using a structure based on our acquisition experience, we revised the models, taking into account both the statistical properties of the models and our operational knowledge of acquisition.

The use of a cross-sectional, time-series analysis allowed us to introduce multiple observations of the acquisition program and the associated contracts into the complete dataset across the program reporting times identified in the SARs. In this type of cross-

sectional, time-series analysis, the statistical tests are identical to those applicable in traditional regression analysis. Based on our experience, we felt that the use of fixed-price contracts during EMD would affect program outcomes; however, there were no programs in which fixed-price contracts were the predominant contract type during EMD. Because there were programs in which the predominant contract type was fixed price during the production phase of the acquisition process, we examined this categorical variable. We extracted the contract type data associated with RDT&E appropriations in order to compare it to the predominant contract type in the production phase.

## E. CONCEPTUAL MODELS

As indicated, our objective in this research is to determine the likely effects of the increased usage of fixed-price contracts during the acquisition process on program and contract costs. In order to meet this objective, we designed an interrelationship model of the variables. Figure 10 contains the basic variables and displays the conceptual hypotheses of how contract type affects contract variances and, ultimately, how it affects program variances. These variances are measured in dollars over time, and the factors also correspond to the independent and dependent variables we examined in the cross-sectional, time-series analysis.

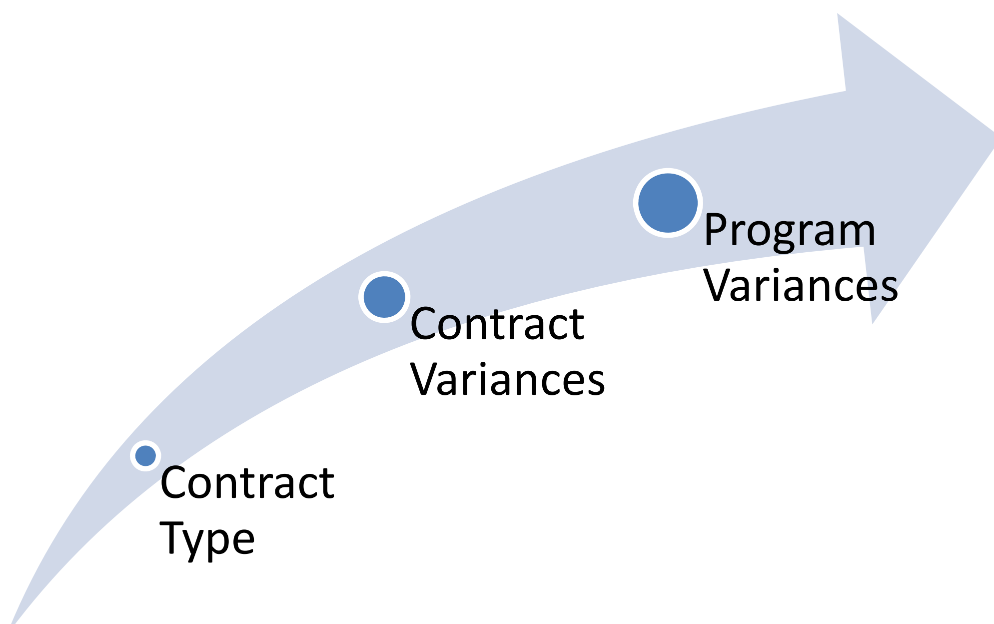


**Figure 10. Flow Diagram of Conceptual Hypothesis**

## F. SUMMARY

In this chapter, we described our data collection process and displayed some key features of this data. We also provided a brief discussion of the statistical methods we used for our analysis. These methods included descriptive statistics and multiple regression analysis. In the next chapter, we continue our discussion of methodology and report the results of the statistical analysis we conducted.

# V. STATISTICAL METHODOLOGY AND RESULTS

## A. OVERVIEW

In this chapter, we initially provide a discussion of regression analysis as it relates to our exploratory models. We then provide an explanation of the results from our analyses and answer the research questions we proposed in Chapter I. We identify the relationship between both program and contract cost, and program and contract variances, as programs progress through development to production. Understanding these interrelationships should help acquisition professionals better manage cost, schedule, and technical risk in MDAPs.

## B. MULTIPLE REGRESSION ANALYSIS

The primary analytical tool used in this chapter is multiple regression analysis. This technique estimated the effect of a number of specified explanatory variables on a particular dependent variable. In this analysis, we employed historical observational data, and researchers can expect these variables to be correlated with each other.

However, multiple regression analysis is designed to deal with this issue. When one of the explanatory variables changes, the others are statistically held constant so the effect of the changing explanatory variables on the dependent variables is isolated.

It is important to appreciate that a multiple regression model with a low $R^2$ can still have important uses. When *t*-statistics are statistically significant at the same time as the $R^2$ is low, the model can be used to accurately estimate the change in the dependent variables when a particular policy variable changes. In this situation, we can have a valid policy response model.

In forecasting models, the $R^2$ typically needs to be large. However, it remains true that in policy response models with low $R^2$ and high *t*-statistics, researchers can accurately predict the value of dependent variables for a group of cases with like values for the explanatory variables, even though there may be significant uncertainty associated

with predicting for an individual case. It is frequently the case that policy is made based on what is likely to happen on average (Gilster, 1970).

In this analysis, we also make extensive use of categorical variables that are formed from some group and that take on a value of 1 if some condition holds—for example, a specific type of contract—and 0 otherwise. In the case of contract type, as an example, one of the contract types is selected as the reference category and excluded from the model. The size and significance of the group's included explanatory variables are always evaluated relative to the excluded categorical variables. Therefore, if an included categorical variable is not statistically significant, this means that it is not significantly different from the excluded variable.

It is our expectation that the current analysis will be followed by subsequent analyses, and that, as a result, a consensus may emerge as to the appropriate specification that accurately reflects the underlying causal structure. Then, it will be possible to determine whether the data are consistent with this causal structure. However, we view our regression analyses as exploratory in nature, and this, in turn, resulted in several decisions as to how to display the results.

For example, when the binary variables that are members of a particular group are all non-significant, we frequently display the results obtained. While an alternative would be to simply state that none of the binary variables are significantly different from each other, including all of the non-significant binary variables may aid future analysts who build upon our work.

Also, a variable believed to be important to the analysis that has the predicted sign, but which is statistically very insignificant, may be retained in the model. This can also aid future analysts who believe this variable to be important and choose to include it in a model with a different specification.

We have also limited our exploratory examination to the estimation of a number of single-equation regression models. Linked regression model that contain more than a single equation are not included. For example, we did not evaluate an empirical path in which, say, contract schedule variance and other variables affect, say, program

engineering variance, which, in conjunction with other explanatory variables, affects net program variance. This type of path-analysis modeling awaits additional research.

## C. DEFINITION OF VARIABLES

### 1. Types of Data

We now provide more detail on the types of data employed. As discussed in Chapter IV, the variables used in this research can be grouped into two categories: numerical and nominal. Numerical data can be compared using regression and other means, but nominal data cannot be directly compared. Instead, nominal variables must be converted to a series of binary variables, which are also frequently called dummy variables. Accordingly, dummy variables used in the research end in "_D."

### 2. Binary Variables

As indicated previously, binary variables indicate the presence or lack of presence of a category or condition. Two or more categories may be compared using dummy variables. For example, two types of acquisitions are considered in this research: new start acquisitions and modification acquisitions. Acquisition type is represented by the variables "AcqType_Mod_D" and "AcqType_New_D." When the value of AcqType_Mod_D is 1, this indicates that the MDAP is a modification program; when the value is 0, the MDAP is a new start program. When the value of AcqType_New_D is 1, this indicates that the MDAP is a new start program. Because the sum of these two variables necessarily equations 1, one of the two would be selected for explicit use in the regression, and the other would be the reference variable.

As indicated, when examining the effect of a dummy variable, readers should keep in mind the variable's reference. The reference for AcqType_Mod_D is AcqType_New_D. Therefore, for regressions including AcqType_Mod_D, the effect of a modification acquisition relative to the effect of a new start acquisition is shown as the regression coefficient. This coefficient measures the difference found in the data between when AcqType_Mod_D equals one and when it equals zero.

The remaining dummy, categorical, and scale variables mentioned in the model are listed below, broken down by type and program or contract relationship.

#### *a. Additional Program Variables*

EMD_D: 1 indicates the presence of the EMD phase; 0 indicates the presence of the production phase.

RDTE_D: 1 indicates the presence of an RDT&E appropriation; 0 indicates another appropriation, typically procurement.

PROC_D: 1 indicates the presence of the procurement phase; 0 indicates another appropriation, typically RDT&E.

AcqSegment_Aircraft_D: 1 indicates the presence of the Aircraft (planes and helicopters) acquisition segment; 0 indicates otherwise.

AcqSegment_C4ISR_D: 1 indicates the presence of the C4ISR acquisition segment; 0 indicates otherwise.

AcqSegment_Missiles_D: 1 indicates the presence of the Missiles acquisition segment; 0 indicates otherwise.

AcqSegment_Ships_D: 1 indicates the presence of the Ships acquisition segment; 0 indicates otherwise.

EMD_FFP_D: 1 indicates FFP as the predominant contract type during EMD; 0 indicates otherwise.

EMD_FPIF_D: 1 indicates FPIF as the predominant contract type during EMD; 0 indicates otherwise.

EMD_CPIF_D: 1 indicates CPIF as the predominant contract type during EMD; 0 indicates otherwise.

EMD_CPAF_D: 1 indicates CPAF as the predominant contract type during EMD; 0 indicates otherwise.

EMD_CPFF_D: 1 indicates CPFF as the predominant contract type during EMD; 0 indicates otherwise.

EMD_CONTOTH_D: 1 indicates Hybrid/Other as the predominant contract type during EMD; 0 indicates otherwise.

RDTE_FFP_D: 1 indicates FFP as the predominant contract type for RDT&E; 0 indicates otherwise.

RDTE_FPIF_D: 1 indicates FPIF as the predominant contract type for RDT&E; 0 indicates otherwise.

RDTE_CPIF_D: 1 indicates CPIF as the predominant contract type for RDT&E; 0 indicates otherwise.

RDTE_CPAF_D: 1 indicates CPAF as the predominant contract type for RDT&E; 0 indicates otherwise.

RDTE_CPFF_D: 1 indicates CPFF as the predominant contract type for RDT&E; 0 indicates otherwise.

RDTE_CONTOTH_D: 1 indicates Hybrid/Other as the predominant contract type for RDT&E; 0 indicates otherwise.

PROD_FFP_D: 1 indicates FFP as the predominant contract type during production; 0 indicates otherwise.

PROD_FPIF_D: 1 indicates FPIF as the predominant contract type during production; 0 indicates otherwise.

PROD_CPIF_D: 1 indicates CPIF as the predominant contract type during production; 0 indicates otherwise.

PROD_CPAF_D: 1 indicates CPAF as the predominant contract type during production; 0 indicates otherwise.

PROD_CPFF_D: 1 indicates CPFF as the predominant contract type during production; 0 indicates otherwise.

PROD_CONTOTH_D: 1 indicates Hybrid/Other as the predominant contract type during production; 0 indicates otherwise.

EMD_BasicContractType_CP_D: 1 indicates a cost-plus basic contract type as the predominant basic contract type during EMD; 0 indicates otherwise.

EMD_BasicContractType_FP_D: 1 indicates a fixed-price basic contract type as the predominant basic contract type during EMD; 0 indicates otherwise.

RDTE_BasicContractType_CP_D: 1 indicates a cost-plus basic contract type as the predominant basic contract type for RDT&E; 0 indicates otherwise.

RDTE_BasicContractType_FP_D: 1 indicates a fixed-price basic contract type as the predominant basic contract type for RDT&E; 0 indicates otherwise.

PROD_BasicContractType_CP_D: 1 indicates a cost-plus basic contract type as the predominant basic contract type during production; 0 indicates otherwise.

PROD_BasicContractType_FP_D: 1 indicates a fixed-price basic contract type as the predominant basic contract type during production; 0 indicates otherwise.

#### *b. Contract Variables*

FFP_D: indicates a contract is FFP; 0 indicates otherwise.

FPIF_D: indicates a contract is FPIF; 0 indicates otherwise.

CPIF_D: indicates a contract is CPIF; 0 indicates otherwise.

CPAF_D: indicates a contract is CPAF; 0 indicates otherwise.

CPFF_D: indicates a contract is CPFF; 0 indicates otherwise.

CONTOTH_D: indicates a contract is Hybrid/Other; 0 indicates otherwise.

FFP_EMD_CaseContractType_D: 1 indicates an FFP contract during EMD; 0 indicates otherwise. As such, the coefficients of FFP_D and FFP_EMD_CaseContractType_D can be summed to determine the performance of FFP

during EMD. The remaining Case Contract Type variables should be interpreted in the same manner.

FPIF_EMD_CaseContractType_D: 1 indicates an FPIF contract during EMD; 0 indicates otherwise.

CPIF_EMD_CaseContractType_D: 1 indicates a CPIF contract during EMD; 0 indicates otherwise.

CPAF_EMD_CaseContractType_D: 1 indicates a CPAF contract during EMD; 0 indicates otherwise.

CPFF_EMD_CaseContractType_D: 1 indicates a CPFF contract during EMD; 0 indicates otherwise.

CONTOTH_EMD_CaseContractType_D: 1 indicates a Hybrid/Other contract during EMD; 0 indicates otherwise.

### 3. Categorical Variables Without Dummy Equivalents

#### *a. Program Variable*

ProgramID: A unique program identification number associated with a contract representing a single scope of work.

#### *b. Contract Variable*

ProgramandContractID: A unique contract identification number associated with a contract representing a single scope of work. This identification number is separate and distinct from a contract's contract number.

### 4. Scale Variables

#### *a. Program Variables*

MilestoneBscheduleachieved_Fractional_Year: The year in which Milestone B was achieved, represented numerically as whole years with decimal partial years.

Program_Fractional_Year: The number of years since formal program inception (typically at Milestone B), represented numerically as whole years with decimal partial years.

SARBaselineProdEstConstant2010$M: The program baseline cost estimate. This variable and the remaining variables labeled Constant2010$M are presented in constant 2010 millions of dollars.

Program Schedule Variance, Constant2010$M: The current period cost variance attributable to schedule changes.

Program Engineering Variance, Constant2010$M: The current period cost variance attributable to engineering changes.

SubtotalCurrentChangesConstant2010$M: The current total cost variance.

CECostVarianceConstant2010$M: This is the expected program cost through the end of production and is the sum of the program baseline cost estimate, prior cost variance, and current cost variance.

Program Cost Variance, Constant2010$M: The current period cost variance attributable to any program change, with the exception of schedule and engineering changes. This variance is also presented in constant 2010 millions of dollars.

CurrentLessInitialProgramCost: The current estimate of program cost minus the initial estimate of program cost, presented in constant 2010 millions of dollars.

#### *b. Contract Variables*

TargetInitialContractPrice$M: The initial target contract price target in millions of dollars.

TargetCurrentContractPrice$M: The current target contract price in millions of dollars.

ProgramManagerEstimatedPriceAtCompletion$M: The current program manager’s contract estimated price at completion in millions of dollars.

Contract Cost Variance: The contract earned value cost variance in millions of dollars.

Contract Schedule Variance: The contract earned value schedule variance in millions of dollars.

CurrentLessInitialContractPrice: The current estimate of contract price minus the initial estimate of contract price in millions of dollars.

ContractEACLessInitialContractPrice: The current contract estimate at completion minus the initial estimate of contract price in millions of dollars.

ContractEACLessCurrentContractPrice: The current contract estimate at completion minus the current estimate of contract price in millions of dollars.

For an alphabetized list of the variables used see Appendix A.

## D. RESEARCH QUESTIONS

### 1. Primary Questions

1. What effect does fixed-price R&D have on production cost, schedule, and technical performance?

Table 2 in Chapter IV showed the predominant contract type computed for RDT&E appropriation. There were three programs (CH-47F, NAS, and SSN 774) with predominant fixed-price contracts for RDT&E. In order to answer this research question, we computed the average CV, SV, and EV for all 31 MDAPs in the sample to contrast the effects of predominant fixed-price RDT&E contracts on the three MDAPs. The averages are listed in Table 4

.

**Table 4. Average Program Variances for Entire Sample and Predominant FP in RDT&E (2010 $M)**

| | CV | SV | EV |
|---|---|---|---|
| Average Program Variance all MDAPs | 3093.6 | 366.5 | 651.6 |
| Average Program Variance of Predominant FP Contracts in RDT&E | 9306.0 | 614.0 | 685.3 |

Table 4 shows that the average CV for the entire sample of MDAPs was $3,093.6 million, while the average CV for predominant fixed-price RDT&E contracts was $9,306 million, or an average CV increase of over $6 billion. There were only three programs with predominant fixed-price RDT&E contracts, which do not make these observations compelling evidence. We would assume that fixed-price contracts would assist in controlling program costs, but the use of fixed-price contracts during RDT&E is associated with larger CV.

Table 4 also identifies the average SV on predominant fixed-price RDT&E contracts to be approximately $250 million higher than the sample, and EV was only higher by approximately $35 million. These figures, although computed on three programs, show that the predominant use of FP contracts during RDT&E is associated with higher SV.

2. Do different segments of MDAPs (e.g., fighters, tanks, missiles, satellites) exhibit differing cost and schedule growth?

We categorized the 31 MDAPs into four segments: A, M, R, and S. These segments are defined in Table 5, with the number of programs for each category shown in the total column.

Table 5. **MDAP Segment**

| CODE | SEGMENT CATEGORIES | Total |
|---|---|---|
| A | Aircraft (plane, helicopter) | 14 |
| M | Missile, weapons, ammunition | 10 |
| R | C4ISR | 6 |
| S | Ship, submarine | 1 |
| | | **31** |

We also categorized the MDAPs into two types: modernization and new start. There were 10 modernization and 21 new start programs. To calculate average cost growth for each segment, we calculated the total cost growth (including both cost overruns and cost underruns) by subtracting the original SAR baseline from the latest program estimate, dividing by the number of years, and then dividing by the original SAR baseline.[2] This formula is shown in Figure 11.

$$\text{Average Cost Growth \%} = \frac{\dfrac{\text{(Latest Program Estimate – SAR Original Baseline)}}{\text{Number of SAR Years}}}{\text{SAR Original Baseline}}$$

**Figure 11. Average Cost Growth Formula**

To calculate schedule growth over the course of a program for each segment, we divided the total schedule variance (including both schedule overruns and schedule underruns) by the current SAR baseline. This formula is shown in Figure 12.

$$\text{Average Schedule Growth \%} = \frac{\text{Total Schedule Variance}}{\text{SAR Current Baseline}}$$

**Figure 12. Average Schedule Growth Formula**

We calculated each program's cost and schedule growth and averaged this by segment, shown in Table 6 for easy comparison. The Virginia Class Submarine was the

[2] The segment average cost growth was computed from the annual average growth percentage rate of each program.

only program in the ship and submarine category; thus, it should not be considered as an average of the segment. The other three categories have a similar average cost growth, with aircraft topping the segments with 10.3% growth. The average schedule growth between the three categories varied greatly, with aircraft having the least amount of growth and the C4ISR segment averaging 13.4% growth in schedule.

**Table 6. Average Program Cost and Schedule Growth by MDAP Segment**

| # of MDAPs | SEGMENT CATEGORIES | Average Cost Growth | Average Schedule Growth |
|---|---|---|---|
| 14 | Aircraft (plane, helicopter) | 10.33% | 1.57% |
| 10 | Missile, weapons, ammunition | 7.20% | 3.18% |
| 6 | C4ISR | 9.87% | 13.42% |
| 1 | Ship, submarine | 2.96% | 2.65% |

3. Does early cost, schedule, or engineering variance serve as a leading indicator of later-period CV, SV, and/or EV in either EMD or post Milestone C?

Examining this research question required the use of multiple regressions, which we discuss in further detail in Section D. The regressions applicable to the interrelationship of variances can be found at the end of Section D.

### 2. Secondary Questions

1. What portion of MDAPs have fixed-price incentive R&D contracts?

Based on the 31 programs and 904 contracts in the dataset, there were 32 fixed-price contracts issued during EMD from a total of 369 RDT&E-appropriated CLINs. Less than 9% of the 369 RDT&E contracts were fixed-price. The initiative promoting fixed-price R&D contracts is rather new, and the small number of FP contracts is not surprising. Future research is recommended to investigate the increase of FP contracts used for RDT&E appropriation.

2. Is there qualitative information to support the assertion that fixed-price contracts during the EMD phase hinder the identification of program problems?

The discussion of contract types and preferred contract types by acquisition phase in Chapter II and the discussion of the importance of R&D outcomes in Chapter III are

consistent with the assertion that fixed-price contracts may be associated with problem identification in the development process.

3. If the effect of fixed-price R&D is measurable, are the variances larger with regard to cost, schedule, or engineering during EMD and production?

This question can be addressed as a continuation of primary research question 1. The CV, SV, and EV for predominant fixed-price contracts under RDT&E were compared to the entire dataset. The average CV, SV, and EV for predominant FP contracts during production was calculated and compared to the dataset listed in Table 7.

**Table 7. Average Program Variances for Entire Sample and Predominant FP in RDT&E and Production (in $ millions)**

| | CV | SV | EV |
|---|---|---|---|
| Average Variance all MDAPs | 3093.6 | 366.5 | 651.6 |
| Average Variance of Predominant FP Contracts in RDT&E | 9306.0 | 614.0 | 685.3 |
| Average Variance of Predominant FP Contracts in Production | 3889.9 | 333.7 | 842.9 |

The average variance for predominant fixed-price contracts in production was very similar to the entire dataset except for engineering variance. The average EV increase of $191 million occurring on predominant fixed-price contracts during production phase could be attributable to increased technical risk experienced during the production phase. Even fixed-price contracts might not be able to hedge the technical risk. The ceiling price might provide incentives for a contract change to be approved. Engineering changes occur due to new technology upgrades, redesign, and configuration changes. Minimizing changes would be the best prevention of poor engineering variances. Further analysis might relate this finding to the associated contract type used during the EMD phase.

4. Based on the results found in this research, can any definitive policy recommendations be made?

Our discussion in Chapter VI of the results and recommendations answers this research question.

## E. MULTIPLE REGRESSION ANALYSIS

We conducted a regression analysis to identify the relationship between cost and price changes at the program and contract levels. These regressions partially formed the basis of our responses earlier in this chapter to the research questions we posed in Chapter I. In this section, we also explore regression relationships in greater detail by focusing on establishing the statistical validity of the data, given our knowledge of the acquisition process, rather than on responding directly to any specific research question. This was done using the stepwise method favored by most statisticians for exploratory regressions (Hair et al., 2009). Following the stepwise method, we began with initial regressions and iteratively improved these regressions until arriving at satisfactory final regressions. Differing initial and final regressions were run based upon the relationships we were attempting to quantify.

We focused our modeling efforts, first, on relating cost and price changes over time at the program and contract levels. Then, we related cost, schedule, and engineering variances at the program level and earned value cost and schedule variances at the contract level. The remaining variables were included because, based on our knowledge of the acquisition process, we believed that they could have an effect on the dependent variables. After developing program and contract models, we examined models in which program data was related to contract data.

### 1. Regressions of Cost and Price Changes at the Program and Contract Levels

We focused our modeling effort on relating cost and price changes over time at the program and contract levels; this focus arose from the general trend in contract and program cost growth over time, as illustrated in Figure 13. Program cost estimates for a given SAR estimate the cost of an MDAP through the end of production. Contract cost estimates for a SAR estimate the cost of the contract through the end of the contract in two forms: the current target price and estimate at completion (EAC). The current target price is the current negotiated contract price. The EAC is an independent estimation of the final contract price, based upon the expected price of definitized work, undefinitized

work, and contract overruns. Our research uses the government program manager's EAC.

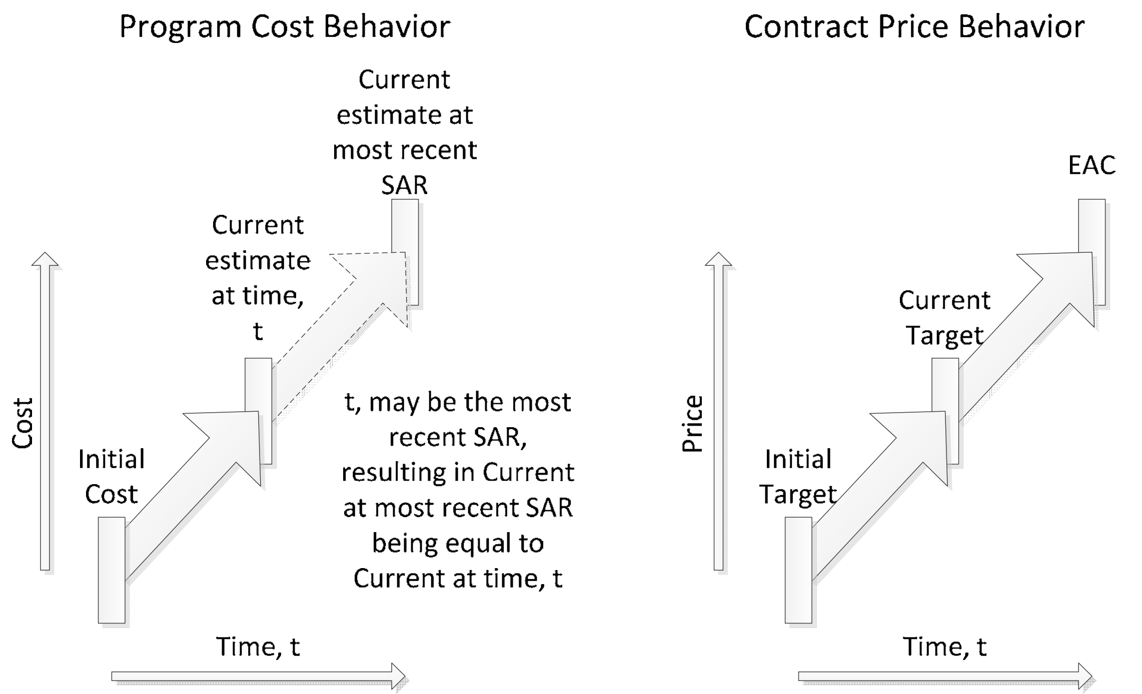


**Figure 13. Typical Program and Contract Cost Growth Over Time**

This typical pattern suggests multiple avenues for studying the causes of program cost growth, added contract scope, contract overruns, and their interrelationships. For this research, program cost growth is defined as the current estimate at time, *t*, minus the initial cost. To better explore the relationship between program cost growth and contract price growth, we first examined the relationship between program cost growth and contract growth using the same explanatory variables included in the program cost regression, but adding contract-level variables. Acquisition segment, acquisition type, predominant basic contract type during production, predominant basic contract type for RDT&E, the years since program inception, the year that a program achieved MS B, and acquisition phase were each included as variables that explain program cost growth. The initial program cost growth model examined is shown in Table 8.

**Table 8. Initial Regression of Program Cost Growth (Current Estimate—Initial Cost)**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| 1 | (Constant) | -35576.462 | 123146.728 | -.289 |
| | AcqSegment_Aircraft_D | -16700.178 | 1083.424 | -15.414 |
| | AcqSegment_C4ISR_D | -16792.475 | 1048.513 | -16.016 |
| | AcqSegment_Missiles_D | -16228.618 | 1071.707 | -15.143 |
| | AcqType_Mod_D | 1741.443 | 600.233 | 2.901 |
| | PROD_BasicContractType_FP_D | -587.125 | 654.329 | -.897 |
| | RDTE_BasicContractType_FP_D | -236.511 | 800.872 | -.295 |
| | Program_Fractional_Year | 215.176 | 55.684 | 3.864 |
| | MilestoneBscheduleachieved_Fractional_Year | 25.898 | 61.468 | .421 |
| | EMD_D | -1688.308 | 647.847 | -2.606 |
| Dependent Variable: CurrentLessInitialProgramCost | | | $R^2$ = .448 | N = 827 |

After exploring multiple possible alterations to the model, we eliminated variables with non-significant *t*-statistics, namely the predominant basic contract type for RDT&E and the year that a program achieved MS B. The resultant final regression, shown in Table 9, has significant *t*-statistics and a slightly improved $R^2$.

**Table 9. Final Regression of Program Cost Growth (Current Estimate—Initial Cost)**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| 1 | (Constant) | 15820.918 | 887.255 | 17.831 |
| | AcqSegment_Aircraft_D | -16458.915 | 700.657 | -23.491 |
| | AcqSegment_C4ISR_D | -16371.119 | 810.449 | -20.2 |
| | AcqSegment_Missiles_D | -16499.36 | 691.423 | -23.863 |
| | AcqType_Mod_D | 1770.771 | 482.723 | 3.668 |
| | PROD_BasicContractType_FP_D | -256.852 | 514.441 | -0.499 |
| | Program_Fractional_Year | 186.603 | 41.862 | 4.458 |
| | EMD_D | -1493.173 | 598.052 | -2.497 |
| Dependent Variable: CurrentLessInitialProgramCost | | | $R^2$ = .449 | N = 879 |

The dummy variables in the acquisition segment category should be viewed in light of their relationship to their reference dummy variable, the acquisition segment

Ships dummy variable. The modification acquisition type dummy should be viewed in light of its relationship to the new start acquisition type dummy. Therefore, the coefficients shown for each dummy should be viewed in light of their reference—not in absolute terms. From this regression, we can determine that the acquisition segment dummies are each significantly different from their reference, Ships; each segment has program cost growth that is significantly less than Ships in relative terms. We can also determine that modification acquisitions experience relatively higher cost growth than new start acquisitions. The regression also shows that programs that use a contract from the fixed-price family of contracts (FFP, FPIF, FPIS, or FPEPA) during production experience lower cost growth than those that do not, although not at a significant level. This variable is retained in the model as an aid to those doing follow-on work. The regression also shows that programs experience significantly lower cost growth during EMD than during production; this is even more significant given that the regression also shows that cost growth significantly increases as the time since a program has achieved MS B increases.

The next model examined the causes of contract price growth. We defined contract price growth as the contract estimate at completion (EAC) minus the contract initial target price. To better explore the relationship between program cost growth and contract price growth, we examined the relationship between contract price growth and the variables we intended to hold constant for our later regression of program cost growth on contract cost growth. Acquisition phase, predominant contract type during EMD, acquisition type, acquisition segment, predominant basic contract type for RDT&E, the year that a program achieved MS B, and the years since program inception were each used as variables for explaining contract price growth. The initial contract price-growth model is shown in Table 10.

Table 10. **Initial Regression of Contract Price Growth (EAC—Initial Target)**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 4877.025 | 17424.792 | .280 |
| | EMD_D | 163.065 | 92.847 | 1.756 |
| | EMD_CPAF_D | 433.518 | 69.075 | 6.276 |
| | EMD_CPIF_D | 153.400 | 83.308 | 1.841 |
| | EMD_CPFF_D | -229.607 | 84.751 | -2.709 |
| | AcqType_Mod_D | -560.877 | 88.288 | -6.353 |
| | AcqSegment_Aircraft_D | 420.955 | 115.949 | 3.631 |
| | AcqSegment_C4ISR_D | -115.839 | 124.353 | -.932 |
| | AcqSegment_Missiles_D | 18.759 | 117.219 | .160 |
| | MilestoneBscheduleachieved_Fractional_Year | -2.454 | 8.707 | -.282 |
| | Program_Fractional_Year | 10.664 | 8.308 | 1.284 |
| Dependent Variable: ContractEACLessInitialContractPrice | | | $R^2$ = .163 | N = 891 |

After exploring multiple possible alterations to the model, we eliminated a variable with a non-significant *t*-statistic, the variable representing the year that a program achieved MS B. We also substituted specific contract type for each contract for predominant contract type during EMD. The resultant final regression, shown in Table 11, has an improved $R^2$.

Table 11. **Final Regression of Contract Price Growth (EAC—Initial Target)**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 132.035 | 168.037 | .786 |
| | AcqSegment_Aircraft_D | 426.880 | 121.139 | 3.524 |
| | AcqSegment_C4ISR_D | 20.141 | 127.703 | .158 |
| | AcqSegment_Missiles_D | 67.671 | 121.148 | .559 |
| | AcqType_Mod_D | -340.531 | 74.202 | -4.589 |
| | Program_Fractional_Year | 28.110 | 6.725 | 4.180 |
| | EMD_D | 107.048 | 91.870 | 1.165 |
| | CPIF_D | -346.545 | 126.150 | -2.747 |
| | FFP_D | -461.813 | 116.671 | -3.958 |
| | FPIF_D | -295.845 | 142.762 | -2.072 |
| | CPAF_D | 252.499 | 124.183 | 2.033 |
| | CPFF_D | -402.172 | 138.872 | -2.896 |
| Dependent Variable: ContractEACLessInitialContractPrice | | | $R^2$ = .189 | N = 891 |

The contract type dummy variables should be viewed in light of their reference, namely, the contract type dummy variable in the Hybrid/Other segment. The only contract type with more growth than the reference contract type was CPAF. The reasons for the relative price increase cannot be determined from Table 11. However, larger price

growth indicates that either contract overruns or scope increases resulted in CPAF contracts exhibiting greater price growth. This effect is still relative to that displayed by the reference contract type, Hybrid/Other. A similar interpretation applies to the acquisition segment variables.

In the next model, we examined the causes of program cost growth, but this model also included contract price growth as an independent variable. This provides a linkage between the program data and the contract data. Again, we defined program cost growth as current cost minus initial cost. To better understand the output of this combined program cost and contract price growth model, we first ran the regressions above to understand what variables to include in the combined regression. Predominant basic contract type during production, predominant basic contract type for RDT&E, acquisition phase, contract type, acquisition type, acquisition segment, the years since program inception, and the year that a program achieved MS B were each included in the initial model. The initial program cost model, including the independent variable for contract price growth, is shown in Table 12.

**Table 12. Initial Regression of Program Cost Growth (Current Estimate—Initial Cost), Including the Independent Variable for Contract Price Growth**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 87866.712 | 125688.232 | .699 |
| | PROD_BasicContractType_FP_d | -577.344 | 650.660 | -.887 |
| | RDTE_BasicContractType_FP_D | 85.932 | 793.588 | .108 |
| | EMD_D | -1865.279 | 651.506 | -2.863 |
| | CPIF_D | -474.264 | 1038.975 | -.456 |
| | FFP_D | -2526.073 | 972.139 | -2.598 |
| | FPIF_D | -1150.724 | 1099.022 | -1.047 |
| | CPAF_D | -1316.971 | 1015.765 | -1.297 |
| | CPFF_D | -3715.515 | 1088.713 | -3.413 |
| | AcqType_Mod_D | 1311.159 | 615.329 | 2.131 |
| | AcqSegment_C4ISR_D | -16464.854 | 1069.747 | -15.391 |
| | AcqSegment_Missiles_D | -16054.011 | 1084.695 | -14.800 |
| | AcqSegment_Aircraft_D | -15935.673 | 1095.288 | -14.549 |
| | Program_Fractional_Year | 222.874 | 58.269 | 3.825 |
| | MilestoneBscheduleachieved_Fractional_Year | -35.031 | 62.629 | -.559 |
| | ContractEACLessInitialContractPrice | -1.350 | .219 | -6.172 |
| Dependent Variable: CurrentLessInitialProgramCost | | | $R^2$ = .491 | N = 816 |

This initial regression of program cost growth, including the independent variable for contract price growth, had an unexpected negative coefficient for the variable ContractEACLessInitialContractPrice. A negative coefficient would indicate that as contract price growth increases, program cost growth decreases. Following additional analysis, we obtained the result for the final regression, shown in Table 13.

**Table 13. Final Regression of Program Cost Growth (Current Estimate—Initial Cost), Including the Independent Variable for Contract Price Growth**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 17451.266 | 2703.592 | 6.455 |
| | PROD_BasicContractType_FP_D | -774.510 | 895.329 | -.865 |
| | RDTE_BasicContractType_FP_D | 1627.430 | 1481.617 | 1.098 |
| | EMDBCpointdate_D | -2961.289 | 885.129 | -3.346 |
| | CPIF_D | 578.116 | 1846.206 | .313 |
| | FFP_D | 1606.234 | 2039.100 | .788 |
| | FPIF_D | -1001.003 | 1904.692 | -.526 |
| | CPAF_D | -1127.917 | 1872.168 | -.602 |
| | CPFF_D | -2009.671 | 1901.696 | -1.057 |
| | AcqType_Mod_D | 1591.428 | 927.534 | 1.716 |
| | AcqSegment_C4ISR_D | -16412.003 | 1844.091 | -8.900 |
| | AcqSegment_Missiles_D | -15970.579 | 1799.126 | -8.877 |
| | AcqSegment_Aircraft_D | -16507.851 | 1732.202 | -9.530 |
| | Program_Fractional_Year | 170.069 | 77.163 | 2.204 |
| | ContractEACLessCurrentContractPrice | .673 | 1.348 | .499 |
| | Contract Schedule Variance | -55.089 | 20.052 | -2.747 |
| Dependent Variable: CurrentLessInitialProgramCost | | | $R^2$ = .565 | N = 409 |

This final regression, which includes Contract Schedule Variance and switches from CurrentEACLessInitialContractPrice to CurrentEACLessCurrentContractPrice shows that as expected contract price overruns (ContractrEACLessCurrentContractPrice) increase, program cost growth increases. This logic is shown visually in Figure 14. The variable is not statistically significant, but was retained in this exploratory analysis The sign of the contract schedule variance for the current year was negative, which was expected since negative contract variances indicate poor outcomes. Contract Schedule Variance was also significant; thus, a poor contract schedule variance outcome was significant and, therefore, explained significant variation in program cost growth. In other words, an increase in Contract Schedule Variance (a good outcome) can be expected to reduce the final cost of a program (also a good outcome). The fact that the inclusion of Contract Schedule Variance caused the amended contract price variable to switch signs, and lose significance, indicates that the correlations among the contract level variables is sufficiently complex that additional work on the model specification is required.

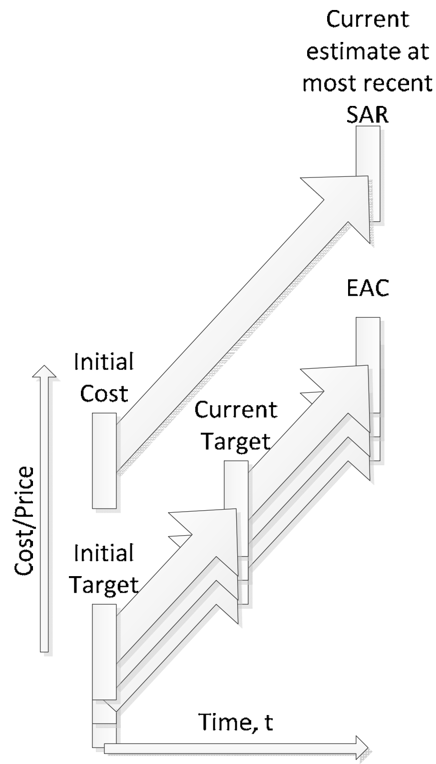


**Figure 14. Typical Program and Contract Cost Growth Over Time**

Figure 14, a notional figure, shows contract EAC growth summing to the growth in the program SAR current estimate. This ignores the fact that programs contain significant government direct expenditures that do not flow through SAR-reportable contracts. These government direct expenditures come from DoD work that complements the contracted efforts, but is not listed in the SAR. The regression in Table 13 follows the expected relationship shown in Figure 14 between contract price growth and program cost growth.

### 2. Regressions of Program and Contract Variances

We focused this portion of our modeling efforts on relating cost, schedule, and engineering variances at the program level and earned value cost and schedule variances at the contract level. To thoroughly examine the effect of variables at both the program and the contract level, we ran regressions in an iterative manner, building to combined

program and contract variance regressions. First, however, we display a correlation table

that contains the simple correlation coefficients among the program and contract variances.

We are reminded that negative contract cost and schedule variances reflect a bad outcome and negative program variances for cost and schedule reflect good outcomes. A positive sign in engineering variance is acceptable if there is a valid rise in the military requirements during the program, which EV captures. The correlations between program and contract variances are shown in Table 14 and significant correlations are highlighted.

**Table 14. Program and Contract Variance Correlations**

**Correlations**

| | | Program Schedule Variances | Program Engineering Variances | Program Cost Variance | Contract Cost Variance | Contract Schedule Variance |
|---|---|---|---|---|---|---|
| Program Schedule Variances | Pearson Correlation | 1 | -.008 | .245** | -.241** | -.280** |
| | Sig. (2-tailed) | | .801 | .000 | .000 | .000 |
| | N | 904 | 904 | 904 | 441 | 441 |
| Program Engineering Variances | Pearson Correlation | -.008 | 1 | .301** | -.147** | .071 |
| | Sig. (2-tailed) | .801 | | .000 | .002 | .137 |
| | N | 904 | 904 | 904 | 441 | 441 |
| Program Cost Variance | Pearson Correlation | .245** | .301** | 1 | -.107* | -.090 |
| | Sig. (2-tailed) | .000 | .000 | | .024 | .058 |
| | N | 904 | 904 | 904 | 441 | 441 |
| Contract Cost Variance | Pearson Correlation | -.241** | -.147** | -.107* | 1 | .224** |
| | Sig. (2-tailed) | .000 | .002 | .024 | | .000 |
| | N | 441 | 441 | 441 | 441 | 441 |
| Contract Schedule Variance | Pearson Correlation | -.280** | .071 | -.090 | .224** | 1 |
| | Sig. (2-tailed) | .000 | .137 | .058 | .000 | |
| | N | 441 | 441 | 441 | 441 | 441 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The correlation table captures the size and significance of the correlations between each of the variances under investigation. Of particular interest are the significant correlations between program-level variances and contract-level variances. Program schedule variance is significantly related to both contract cost variance and contract schedule variance. Program engineering variance is significantly associated with contract cost variance, and program cost variance is significantly associated with contract cost variance. While this table indicates that there are connections among key variances, what is needed are models that isolate the variance connections, holding other variables constant. Therefore, regression analysis is required. Attention will be focused on regression equations in which relevant cost variance is the dependent variable. Other models might be considered in which program schedule variance, program engineering variance, and contract schedule variance are dependent variables, but this is beyond the scope of this research and awaits further analysis.

First, a program variances-only regression was constructed, followed by a contract earned value variances regression. These variance regressions were used to inform the selection of control variables for our combined program and contract variances regression. The intent of the last regression was to establish if there is a direct relationship between the variance metrics used to track programs and the variance metrics used to track contract performance.

The first regression examined was for program cost variance. Program cost variance is composed of multiple components. In this research we focused in part on the relationship of program cost variance to program schedule (SV) and program engineering variance (EV). Since cost variance is composed of SV, EV, and additional categories of cost variance, it is inappropriate to use SV and EV as independent variables, with cost variance as the dependent variable. Doing so could have likely inflated the correlation of SV and EV to cost variance. To resolve this concern, the program variance regressions used cost variance less schedule and engineering cost variances. To simplify the discussion, this is designated as Program Net Cost Variance in the regressions employing this variable.

It should also be noted that all of the variance measures are those reported in the SAR reports for the current period, which is frequently a calendar year. The information on cumulative variance through the period is not employed. Also, all program variance data are measured in FY10 millions of dollars.

The initial regression in which Program Net Cost Variance is the dependent variable, regressed on the explanatory variables, is shown in Table 15. The acquisition segment dummy variables, the modification dummy variable, the EMD-period dummy variable, the year in which MS B was achieved, and the time since program establishment were included to isolate the effect of SV and EV on Program Net Cost Variance. Contract type dummy variables and EMD contract type dummy variables were also used to control for contract type effects. Each contract type dummy variable had an EMD contract type dummy variable associated with it, except for FPIF, which was never the predominant contract type for an EMD contract. The EMD contract type dummy variables, combined with contract type variables not tied to EMD, estimate the effect of contract type during EMD. Therefore, the effect of a contract type dummy variable, which is not identified with EMD, should, when EMD is 0, identify the effect of predominant contract type during production.

Table 15. Initial Regression of Program Cost Variances

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | -34602.05 | 38478.021 | -0.899 |
| | AcqSegment_Aircraft_D | -307.233 | 268.769 | -1.143 |
| | AcqSegment_C4ISR_D | -320.491 | 282.355 | -1.135 |
| | AcqSegment_Missiles_D | -299.473 | 269.202 | -1.112 |
| | AcqType_Mod_D | 239.014 | 175.469 | 1.362 |
| | EMDBCpointdate_D | -282.386 | 527.93 | -0.535 |
| | MilestoneBscheduleachieved_Fractional_Year | 17.612 | 19.197 | 0.917 |
| | Program_Fractional_Year | 3.425 | 18.647 | 0.184 |
| | CPIF_EMD_CaseContractType_D | 31.929 | 605.822 | 0.053 |
| | FFP_EMD_CaseContractType_D | 82.528 | 800.656 | 0.103 |
| | CPAF_EMD_CaseContractType_D | -217.799 | 597.086 | -0.365 |
| | CPFF_EMD_CaseContractType_D | -478.406 | 731.539 | -0.654 |
| | CPIF_D | -70.673 | 319.889 | -0.221 |
| | FFP_D | -245.879 | 288.641 | -0.852 |
| | FPIF_D | -579.157 | 336.471 | -1.721 |
| | CPAF_D | -203.669 | 325.312 | -0.626 |
| | CPFF_D | 508.229 | 346.098 | 1.468 |
| | Program Schedule Variance | 1.13 | 0.307 | 3.679 |
| | Program Engineering Variance | 1.059 | 0.202 | 5.235 |
| Dependent Variable: Program Net Cost Variance, Constant2010$M | | | $R^2$ = .086 | N = 902 |

The very low *t*-statistics found for the Contract Type EMD Case Contract Type dummy variables indicated that these variables should be eliminated unless inserted as a control variable from the final regression. Subsequent regressions (not shown in this research) also revealed that Program_Fractional_Year (the time since program initiation) had a non-significant *t*-statistic; thus, Program_Fractional_Year was removed. The variables in the final program cost variance regression, shown in Table 16, are otherwise the same as those shown in the initial program cost variance regression.

**Table 16. Final Regression of Program Cost Variances**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | -28472.465 | 29499.223 | -0.965 |
| | AcqSegment_Aircraft_D | -342.875 | 262.09 | -1.308 |
| | AcqSegment_C4ISR_D | -330.648 | 277.858 | -1.19 |
| | AcqSegment_Missiles_D | -328.202 | 264.874 | -1.239 |
| | AcqType_Mod_D | 268.756 | 171.754 | 1.565 |
| | EMDBCpointdate_D | -420.883 | 180.665 | -2.33 |
| | MilestoneBscheduleachieved_Fractional_Year | 14.591 | 14.761 | 0.988 |
| | CPIF_D | -78.577 | 273.31 | -0.288 |
| | FFP_D | -281.199 | 252.884 | -1.112 |
| | FPIF_D | -625.172 | 305.184 | -2.049 |
| | CPAF_D | -281.118 | 267.87 | -1.049 |
| | CPFF_D | 404.442 | 298.584 | 1.355 |
| | Program Schedule Variance | 1.13 | 0.306 | 3.687 |
| | Program Engineering Variance | 1.064 | 0.198 | 5.378 |
| Dependent Variable: Program Net Cost Variance, Constant2010$M | | | $R^2$ = .084 | N = 902 |

In the final model, the $R^2$ dropped slightly, but the remaining *t*-statistics improved enough to justify eliminating the EMD contract type dummy variables. The program segment variables are not statistically different from the reference Ships binary variables. The Milestone B variable is retained for future consideration in a re-specified model, and only the FPIF binary variable is significantly lower than the reference Hybrid contract variable. Notice that the largest negative effect occurred when FPIF was the predominant contract type. However, because FPIF was never a predominant contact type during EMD, this result cannot be applied to a hypothetical situation in which an FPIF contract was the predominant contract type during the EMD phase. The positively significant effect of program schedule variance and program engineering variance on Program Net Cost Variance (program cost variance less schedule and engineering variance) is an important finding. The coefficients of these two variables are close to 1, so that, other things being equal, a one dollar increase in each of these variables increases Program Net Cost Variance by about one dollar.

The next regression examined was for contract earned value variances. This regression sought to better understand the effect of contract schedule variance on contract

cost variance. The initial regression controlled for contract type using contract type dummy variables, including contract dummy variables designed to estimate the effect found during EMD. The initial regression of contract cost variances on the selected explanatory variables is shown in Table 17.

**Table 17. Initial Regression of Contract Variances**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 0.531 | 9.482 | 0.056 |
| | CPIF_EMD_CaseContractType_D | 3.014 | 9.549 | 0.316 |
| | FFP_EMD_CaseContractType_D | -0.874 | 46.412 | -0.019 |
| | CPAF_EMD_CaseContractType_D | -4.001 | 8.481 | -0.472 |
| | CPFF_EMD_CaseContractType_D | 3.685 | 16.496 | 0.223 |
| | CPIF_D | -7.03 | 10.593 | -0.664 |
| | FFP_D | 0.343 | 13.27 | 0.026 |
| | FPIF_D | 4.201 | 10.933 | 0.384 |
| | CPAF_D | -7.461 | 10.526 | -0.709 |
| | CPFF_D | -7.733 | 11.499 | -0.672 |
| | Contract Schedule Variance | 0.797 | 0.164 | 4.867 |
| Dependent Variable: Contract Cost Variance | | | $R^2$ = .061 | N = 441 |

We found that increases in contract schedule variance have a significant positive effect on contract cost variance. Contract type, whether interacting or not interacting with EMD, does not have a significant effect on contract cost variance relative to the reference contract.

After examining multiple iterations of the model, we examined the final regression of contract cost variance. This revised model eliminated the dummy variables in which EMD is tied to contract type because of poor *t*-statistics. After revising the initial hypothesis and specifying that acquisition segment dummy variables, the modification acquisition type, date at which MS B was achieved, and the years since MDAP inception belong in the model, we obtained the results shown in Table 18.

**Table 18. Final Regression of Contract Cost Variance**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | -1141.612 | 1444.43 | -0.79 |
| | AcqSegment_Aircraft_D | 14.983 | 8.857 | 1.692 |
| | AcqSegment_C4ISR_D | 26.301 | 9.484 | 2.773 |
| | AcqSegment_Missiles_D | 24.144 | 9.246 | 2.611 |
| | AcqType_Mod_D | 8.303 | 7.214 | 1.151 |
| | MilestoneBscheduleachieved_Fractional_Year | 0.555 | 0.721 | 0.769 |
| | Program_Fractional_Year | 1.142 | 0.678 | 1.685 |
| | CPIF_D | -2.89 | 10.417 | -0.277 |
| | FFP_D | 4.183 | 13.492 | 0.31 |
| | FPIF_D | 11.941 | 11.369 | 1.05 |
| | CPAF_D | -4.963 | 10.442 | -0.475 |
| | CPFF_D | 0.437 | 11.376 | 0.038 |
| | Contract Schedule Variance | 0.733 | 0.163 | 4.495 |
| Dependent Variable: Contract Cost Variance | | | $R^2$ = .086 | N = 441 |

Many of the additional variables included are statistically significant. However, the predominant contract type variables continue to be statistically non-significant compared with the reference Hybrid contract. More important, the significant positive relationship between contract schedule variance and earned value cost variance continues to apply. This means that an increase in budgeted cost of work performed less budgeted cost of work scheduled (a positive outcome) is associated with an increase in budgeted cost of work performed less actual cost of work performed (also a positive outcome).

After conducting program variance-only and contract variance-only regressions, we examined the regressions shown in Table 19 with both program and contract variances. The initial regression sought to establish the effect of the contract cost variance, contract schedule variance, program engineering variance, and program schedule variance on Program Net Cost Variance. Additional variables were added to control for the effects of being in EMD and for the predominant contract type by program during EMD.

**Table 19. Initial Regression of Program and Contract Variances**

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | -38.77 | | -0.273 |
| | Program Engineering Variance Constant2010$M | 1.084 | 0.186 | 3.997 |
| | Program Schedule Variance Constant2010$M | 1.729 | 0.232 | 4.771 |
| | EMDBCpointdate_D | -297.978 | -0.071 | -1.463 |
| | EMD_CPIF_D | 692.664 | 0.169 | 3.064 |
| | EMD_CPAF_D | 96.755 | 0.027 | 0.486 |
| | EMD_CPFF_D | 405.657 | 0.08 | 1.579 |
| | Contract Cost Variance | 0.577 | 0.016 | 0.327 |
| | Contract Schedule Variance | -3.517 | -0.028 | -0.572 |
| Dependent Variable: Program Net Cost Variance Constant2010$M | | | $R^2$ = .104 | N = 439 |

With the program engineering and schedule variances included in the regression, the contract cost and contract schedule variances were not significant. We can note from Table 14 that the correlation between program schedule variance and both contract cost variance and contract schedule variance were statistically significant, and the correlation between program engineering variance and contract cost variance was statistically significant. One can conjecture that multicollinearity might have impacted the significance of contract variance variables. In the re-specification of the model, the program variance explanatory variables were deleted, and additional variables were added to determine whether an alternative model might have superior statistical properties. The final regression of program and contract variances resulting from these changes is shown in Table 20.

Table 20. Final Regression of Program and Contract Variances

| Model | | Coefficient | Std. Error | *t*-statistic |
|---|---|---|---|---|
| | (Constant) | 31915.502 | 58874.493 | 0.542 |
| | AcqSegment_Aircraft_D | 150.025 | 365.233 | 0.411 |
| | AcqSegment_C4ISR_D | -296.542 | 391.406 | -0.758 |
| | AcqSegment_Missiles_D | -249.867 | 375.703 | -0.665 |
| | AcqType_Mod_D | -29.488 | 304.061 | -0.097 |
| | EMDBCpointdate_D | 71.881 | 827.471 | 0.087 |
| | MilestoneBscheduleachieved_Fractional_Year | -15.458 | 29.383 | -0.526 |
| | Program_Fractional_Year | -63.91 | 30.814 | -2.074 |
| | CPIF_EMD_CaseContractType_D | -743.446 | 894.203 | -0.831 |
| | FFP_EMD_CaseContractType_D | 1244.68 | 2049.642 | 0.607 |
| | CPAF_EMD_CaseContractType_D | -1061.793 | 903.484 | -1.175 |
| | CPFF_EMD_CaseContractType_D | -1462.308 | 1079.94 | -1.354 |
| | CPIF_D | 132.394 | 509.539 | 0.26 |
| | FFP_D | 34.286 | 604.259 | 0.057 |
| | FPIF_D | -238.723 | 532.09 | -0.449 |
| | CPAF_D | 68.264 | 520.106 | 0.131 |
| | CPFF_D | 517.904 | 541.03 | 0.957 |
| | Contract Cost Variance | -3.281 | 1.939 | -1.692 |
| | Contract Schedule Variance | -10.073 | 6.722 | -1.499 |
| Dependent Variable: SubtotalCurrentChangesConstant2010$M | | | $R^2$ = .062 | N = 439 |

The newly specified regression, which now includes (total) program cost variance, significantly enhances the statistical significance of the contract variances and yields coefficient signs that are expected; increasing contract cost variance and contract schedule variance is correlated with decreasing program cost variances. This negative correlation actually indicates that contract and program variances are traveling in the same direction, since the sign of a good outcome for contracts is positive, while the sign of a good outcome for programs is negative. Therefore, a connection between program-level data and contract-level data was identified. In addition, program fractional year was a statistically significant variable in this revised model.

The understanding of program and contract variances we built using multiple regression analysis supports our model of the relationship between contract price growth and program cost growth, shown in Figure 15.

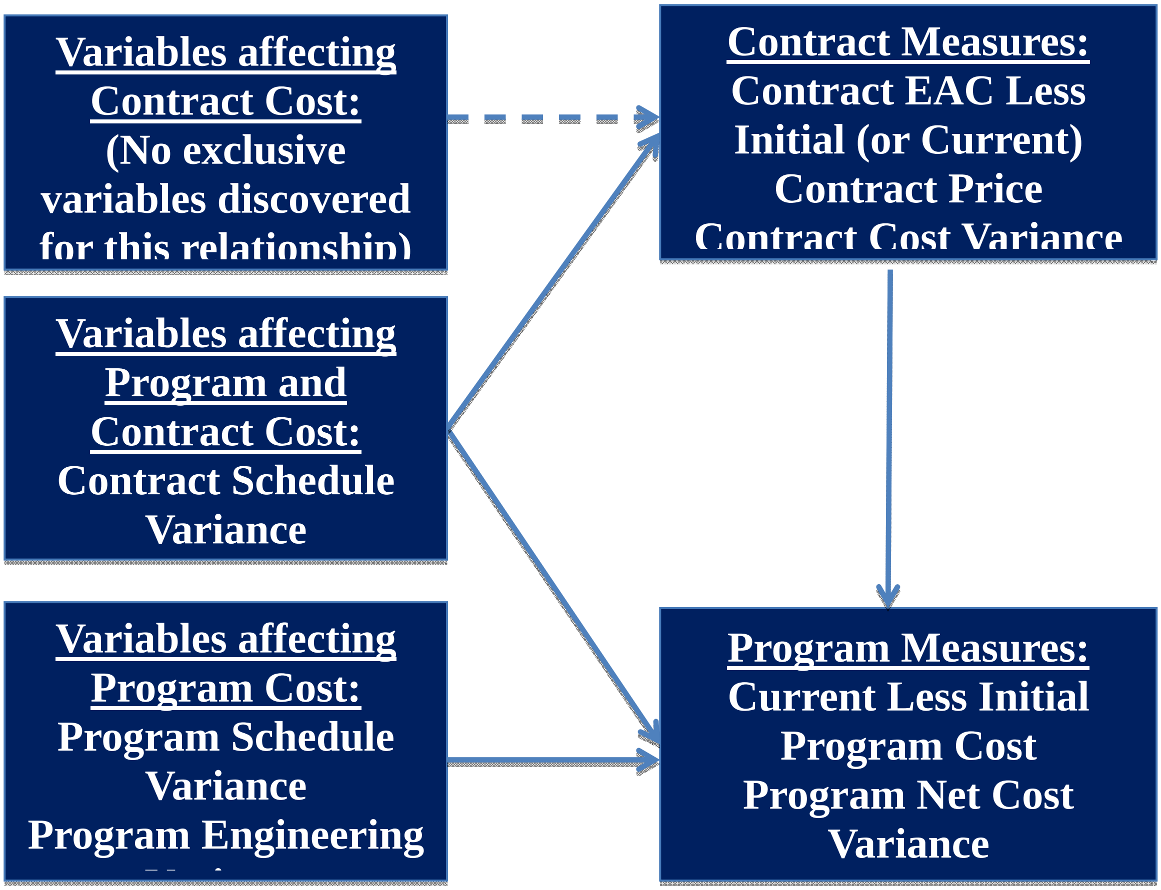


**Figure 15. Relationship Between Variables**

The relationships shown in Figure 15 could form the starting point for further analysis of the relationship between contract price growth and program cost growth. Chapter VI includes suggestions regarding future analysis. Of particular interest is structural equation modeling, which offers the possibility to separate direct and indirect effects between variables affecting both contract price growth and program cost growth.

# VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. DISCUSSION OF RESULTS

This research focused on quantifying relationships between acquisition program attributes, choices, and outcomes. The results recorded in Chapter V, while exploratory in nature, show the relationships that we found in attempting to address each of our research questions. In this chapter, we review those results, idenfity limitations of the study, and present recommendations for further research.

Our results do not provide a definitive conclusion to all of our research questions, but they do offer insights regarding the relationships between program and contract variances, along with contract types. As discussed in this study, one area of potential concern is that the use of fixed-price contracts during R&D may limit contractors' efforts to identify possible technical risks early in a program that would prevent future system design problems. There were only 31 fixed-price contracts started during EMD, and no program had predominant fixed-price contracts during the EMD phase. In this exploratory analysis, the three programs with predominantly fixed-price contracts initiated under RDT&E appropriations performed unfavorably on program costs compared to other contract types in the dataset. This may be attributed to the establishment of a fixed-price contract amount. The CV, SV, and EV all performed worse for programs with fixed-price RDT&E, when compared to the remaining MDAPs. This could be a result of the increased uncertainty and technical risk experienced during RDT&E. Programs with a majority of contract spending on fixed-price contracts during the development phase may not be able to appropriately hedge technical risk. This might be because the ceiling price could provide incentives for a contract change to be approved. Although not conclusive, the use of incentives and award fees may run higher costs and longer schedules, but could prevent expensive future problem identification.

When comparing the different acquisition segment results, C4ISR performed the least favorably, with the highest schedule growth of 13% and the second highest cost growth of 10%. The Aircraft segment had the highest cost growth, just over 10%, but the

lowest schedule growth, 1.5%. The Missiles, weapons, and ammunition segment fell into the middle of the three categories; the single submarine program we analyzed was not comparable to the other segments.

Our findings regarding CV, SV, and EV as leading indicators of later period CV, SV, and EV were only slightly conclusive, in part due to SV and EV not being extensively studied as dependent variables. Our findings regarding CV were partially conclusive. We found that an increase in program year (the number of years since program inception at MS B) was significantly positively correlated with an increase in contract price growth (Table 11) and program cost growth (Tables 9 and 13). Also, an increase in program year was significantly negatively correlated with an increase in program cost variance (Table 20). Program cost growth is a measure of scope increases and overruns, while program cost variance is a measure of changes during the past year to a program's expected cost. The fact that the program year independent variable had opposite and significant signs for the two measures of program cost changes likely indicates that rebaselining significantly impacts the relationship of one or both to program year. Program year had a significant *t*-statistic for the final program variance regression (Table 20) than contract cost variance or contract schedule variance. The strength of this relationship and the opposite effect for program growth and program variance measures could indicate that this variable is actually capturing the effect of rebaselining on program metrics. Rebaselining could be a significant source of the limited correlation between contract variances and program variances in the program variances regression. Further study of the relationship between program variances and further study of the effects of rebaselining could improve the explanatory power of our models.

The results achieved using regressions established preliminary findings. The Aircraft, C4ISR, and Missile segments all showed significantly lower cost growth than Ships. Program managers of ships and submarines should be cognizant of the risk of higher cost growth that exists on already expensive programs. Additionally, regressions showed modifications actually ran higher cost growth than did new starts and initial programs. Although not at a significant level, the predominant use of fixed-price

contracts during production was associated with lower cost growth. This follows our discussion of risk with regard to contract type in Chapter II.

We are one of the first research teams to analyze the relationship of EVM contract variances and program variances. The connection between program and contract variances identified supports the view that contract price growth affects program cost growth. Understanding exactly how program growth is affected by contract growth will allow program managers to better control costs. No conclusive effects were established, but this research has laid the ground work for future research, such as SEM (discussed in Section D), to refine the results achieved.

## B. RECOMMENDATIONS

In this research, we partially confirmed the reservations of acquisition professionals who believe the push for fixed-price R&D from sources such as Under Secretary Carter's (2010) *Better Buying Power* may not always be the best contract type. We also determined that programs with a majority of fixed-price RDT&E contracts tend to have lower cost growth overall and lower cost growth attributable to schedule growth, but higher engineering cost growth compared to all MDAPs. By treating engineering cost growth as a proxy for technical changes, and by considering the attendant technical risks associated with those changes, it is clear that fixed-price RDT&E saves money and time, but increases technical risk. This increased technical risk may be acceptable for RDT&E spending during the production phase, but would likely be unadvisable during EMD, when the costs of discovering problems in systems engineering are substantial.

We examined the use of fixed-price contracts for RDT&E spending in this research, but we did not examine the use of fixed-price contracts during EMD because none of the MDAPs in our sample had fixed-price contracts as the majority contract type for EMD. However, it is possible that fixed-price contracts may be successfully extended into EMD for a limited number of systems, particularly those that exceed the now-strengthened requirements for minimum TRLs. Program managers should proceed with caution, due to the potential for increased technical risk. Only 9% of RDT&E contracts

in our sample were fixed-price, and the vast majority of those were during the production phase.

## C. STUDY LIMITATIONS

The data we used in this study came directly from each program's SAR, including cost variances at the program level and earned value at the contract level. We analyzed a relatively small number of programs (31) due to the limited availability of data that fit our study's requirements and to the labor-intensive nature of the data collection. The dataset included multiple years and contracts for each program, which provided us with a significant number of observations.

SAR data have many limitations that we observed during this study. Although recent changes to regulations driven by WSARA were made in an attempt to reduce rebaselining, our period of study went back as far as 1997 for some programs. Due to shifting rebaselining policy over time, it was difficult to determine the decisions made and the effects of these decisions on variances after a program was rebaselined. After reviewing multiple SAR variances at the program and contract level, there were missing explanations as to the cause of variances required. Multiple SARs had vague information regarding contract type. It appeared that cost variances were allocated inconsistently between SAR categories and between years. The cost information provided for future years reflected projected budget values and was not always consistent with cost estimates. Multiple contract types were listed with no identification of dollar amounts or designation of dominant type.

Even with the limitations in the SARs, we were able to build an extensive dataset. The data also had their own limitations. The low number of fixed-price contracts utilized during the EMD phase prevented us from producing thorough results of the effects of fixed-price development contracts on program variances. Due to a lack of variability in predominant contract type during the EMD phase and due to no program having a predominant fixed-price contract type, we removed those programs with predominant RDT&E contract type to compare differences in production contract type. Also, as we have indicated, the regression analysis must be viewed as exploratory. The models

estimated are a step on the road to hypothesizing causal models that may succeed in obtaining definitive findings.

## D. AREAS FOR FUTURE RESEARCH

### 1. Structural Equation Modeling

In addition to looking at definable, quantitative cost growth, it would also be helpful to examine root sources of variance within programs. In Chapter II, we discussed risk in different acquisition phases. Risk in acquisition programs is an undefined characteristic that program managers continually try to control. Programs have designated risk reserves, but these reserves and levels of uncertainty or risk are not reportable on SARs. Although risks are understood in the acquisition community, they could have direct effects on program or contract variances.

Program risk can be characterized by three subparts: cost, schedule, and technical risk. Once these risks are recognized, the result could include a change in price, schedule, or technology that could ultimately correspond to a program CV, SV, or EV. Any single change could lead to changes throughout a program. For example, funding from Congress could be reduced, affecting the quantity of affordable systems, adjusting the design, and lengthening the schedule.

To allow for the more advanced statistical methods of cross-sectional, time-series analysis, we recommend use of structural equation modeling (SEM) to analyze program and contract variance data. A thorough investigation should be conducted, including an investigation of the use of exploratory factor analysis to identify latent variables, and the results of this investigation should be used to assess the applicability of SEM to program and contract variance data. SEM differs from the prior techniques in its "ability to simultaneously estimate multiple dependence relationships … while also incorporating multiple measures for each [construct]" (Hair et al., 2009, p. 609). Constructs would be the dependent and independent variables included in the analysis. SEM examines both interdependent and dependent relationships simultaneously in a manner akin to combining factor analysis and multiple regression analysis (Hair et al., 2009).

SEM models also permit the simultaneous variance of multiple factors including risk. This method allows the model to include conceptually constructed variables that underlie the measurable variables and could help explain the full effect of fixed-price incentive R&D contracts within MDAPs on later period cost and schedule variance during the production and deployment phases. The use of SEM could allow for the examination of variance of multiple, interrelated, simultaneously varying factors, such as the cost, schedule, and engineering variances of a program and the earned value cost and schedule variances of that program's contracts. At the same time, it incorporates unobserved variables that could be categorized as programmatic risk and its various risk components. These risk measures would mediate the relationship between contract type and other variables, and the program's cost objectives, and thereby clarify the effect of contract type on the desired outcome. The objective of this future research would be to determine the effects of the increased usage of fixed-price R&D contracts during EMD on long-term program CV, SV, and EV. It would also look to determine whether preproduction CV, SV, and EV, and the associated contract variance measures, are indicators of CV, SV, and/or EV and contract performance during production.

### 2. Normality

Unlike regression analysis, normality of the variables is a more important assumption when SEM is employed. Therefore, another area deserving future research is the source of non-normality in program cost variance. This topic would lend itself to research based on frank discussions with past program managers about information hiding and moral hazard in the principal-agent relationship between Congress and program managers. It would also lend itself to further exploration of the characteristics of programs that exhibit drastic deviations from normality.

## F. SUMMARY

In this research we sought to improve understanding of the interrelationship between program and contract metrics by quantifying the relationships between program and contract outcomes. Our exploratory efforts to explain program cost increases using program and contract outcomes resulted in the explanation of 56.6% of program cost

increases. Our efforts to explain program cost variance indicated that only 6.2% of program cost variance could be explained. As indicated previously in this chapter, however, a model of the small portion of the total variance explained when analyzing a response to a policy change, such as a change in contract type, provided the policy change variable is statistically significant. Nevertheless, additional modeling beyond the exploratory effort undertaken here could increase the ability of both models to explain overall program outcomes, and how these change when a particular policy variable changes. This research also attempted to show how preproduction CV, SV, and EV data within acquisition programs affect future variances. The results were not significantly quantifiable, and additional research is recommended. Our results indicated several possible areas of future research, including the non-normality in SAR measures and SEM. Both areas offer the possibility of increasing the effectiveness of the models explored in this project.

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# APPENDIX A. LIST OF VARIABLES FOR ANALYSIS

| Variables used in the research write-up | |
|---|---|
| Name | Explanation |
| AcqSegment_Aircraft_D | 1, if Acquisition Segment is Aircraft; 0, otherwise |
| AcqSegment_C4ISR_D | 1, if Acquisition Segment is C4ISR; 0, otherwise |
| AcqSegment_Missiles_D | 1, if Acquisition Segment is Missiles; 0, otherwise |
| AcqSegment_Ships_D | 1, if Acquisition Segment is Ships; 0, otherwise |
| AcqType_Mod_D | 1, if program Acquisition Type is a modification; 0, otherwise |
| AcqType_New_D | 1, if program Acquisition Type is a new start; 0, otherwise |
| CECostVarianceConstant2010$M | Current Program Cost Estimate through the end of production (in 2010 constant millions of dollars); sum of prior and current cost estimate changes and baseline cost estimate |
| CONTOTH_D | 1, if contract type is Hybrid/Other; 0, otherwise |
| CONTOTH_EMD_CaseContractType_D | COMPUTE CONTOTH_EMD_CaseContractType_D=EMDBCpointdate_d * CONTOTH_D |
| Contract_BasicContractType_CP_D | 1, if CP is Basic Contract Type for an individual contract ; 0, otherwise (FP, fixed price; or CP, cost plus) |
| Contract_BasicContractType_FP_D | 1, if FP is Basic Contract Type for an individual contract ; 0, otherwise (FP, fixed price; or CP, cost plus) |
| ContractEACLessCurrentContractPrice | COMPUTE ContractEACLessCurrentContractPrice=ProgramManagerEstimatedPriceAtCompletion$M - TargetCurrentContractPrice$M |
| ContractEACLessInitialContractPrice | COMPUTE ContractEACLessInitialContractPrice=ProgramManagerEstimatedPriceAtCompletion$M - TargetInitialContractPrice$M |
| ContractID | Contract ID associated with a contract at the program level (NOTE: this Contract ID repeats for each program; e.g. each program has a contract “1.”) |
| ContractName | Contract Name |
| ContractNumber | Contract Number (obtained from SAR and corrected, as necessary, using FPDS) |
| Contractor | Contractor Name |
| ContractType | Contract Type from SAR, adjusted using FPDS data |
| Contract Cost Variance | Current Cost Variances (in millions of dollars) |
| Contract Schedule Variance | Current Schedule Variances (in millions of dollars) |
| CPAF_D | 1, if contract type is CPAF; 0, otherwise |
| CPAF_EMD_CaseContractType_D | COMPUTE CPAF_EMD_CaseContractType_D=EMDBCpointdate_d * CPAF_D |
| CPFF_D | 1, if contract type is CPFF; 0, otherwise |
| CPFF_EMD_CaseContractType_D | COMPUTE CPFF_EMD_CaseContractType_D=EMDBCpointdate_d * CPFF_D |
| CPIF_D | 1, if contract type is CPIF; 0, otherwise |

| | |
|---|---|
| CPIF_EMD_CaseContractType_D | COMPUTE CPIF_EMD_CaseContractType_D=EMDBCpointdate_d * CPIF_D |
| CurrentLessInitialContractPrice | COMPUTE CurrentLessInitialContractPrice=TargetCurrentContractPrice$M - TargetInitialContractPrice$M |
| CurrentLessInitialProgramCost | COMPUTE CurrentLessInitialProgramCost=CECostVarianceConstant2010$M - SARBaselineProdEstConstant2010$M |
| EMD_BasicContractType_CP_D | 1, if CP predominant contract type during EMD; 0, otherwise (CP, Cost Plus; or FP, Fixed Price) |
| EMD_BasicContractType_FP_D | 1, if FP predominant contract type during EMD; 0, otherwise (CP, Cost Plus; or FP, Fixed Price) |
| EMD_CONTOTH_D | 1, if predominant contract type during EMD = Hybrid/Other; 0, otherwise |
| EMD_CPAF_D | 1, if predominant contract type during EMD = CPAF; 0, otherwise |
| EMD_CPFF_D | 1, if predominant contract type during EMD = CPFF; 0, otherwise |
| EMD_CPIF_D | 1, if predominant contract type during EMD = CPIF; 0, otherwise |
| EMD_FFP_D | 1, if predominant contract type during EMD = FFP; 0, otherwise |
| EMD_FPIF_D | 1, if predominant contract type during EMD = FPIF; 0, otherwise |
| EMD_D | 1, if data represents EMD period; 0, if data represents production period |
| EMDpredominantBasicContractType | Predominant contract type during EMD (CP, Cost Plus; or FP, Fixed Price) |
| FFP_D | 1, if contract type is FFP; 0, otherwise |
| FFP_EMD_CaseContractType_D | COMPUTE FFP_EMD_CaseContractType_D=EMDBCpointdate_d * FFP_D |
| FPIF_D | 1, if contract type is FPIF; 0, otherwise |
| FPIF_EMD_CaseContractType_D | COMPUTE FPIF_EMD_CaseContractType_D=EMDBCpointdate_d * FPIF_D |
| MilestoneBscheduleachieved_Fractional_Year | Sum of MilestoneBscheduleachieved_Year + MilestoneBscheduleachieved_Month_12 (NOTE: December 2010 is then represented as 2011.00.) |
| PROC_D | 1, if appropriation is procurement; 0, otherwise |
| PROD_BasicContractType_CP_D | 1, if Cost Plus; 0, otherwise |
| PROD_BasicContractType_FP_D | 1, if Fixed Price; 0, otherwise |
| PROD_CONTOTH_D | 1, if Hybrid/Other; 0, otherwise |
| PROD_CPAF_D | 1, if CPAF; 0, otherwise |
| PROD_CPFF_D | 1, if CPFF; 0, otherwise |
| PROD_CPIF_D | 1, if CPIF; 0, otherwise |
| PROD_FFP_D | 1, if FFP; 0, otherwise |
| PROD_FPIF_D | 1, if FPIF; 0, otherwise |
| PRODpredominantBasicContractType | Predominant basic contract type during production (Fixed Price, FP; or Cost Plus, CP) |
| PRODpredominantContractType | Predominant contract type during production (FFP, FPIF, CPIF, |

| | |
|---|---|
| | CPAF, CPFF, Hybrid/Other) |
| Program_Fractional_Year | Years since program initiation |
| ProgramandContractID | A unique Contract ID associated with a contract representing a single scope of work. To accommodate multiple programs and contracts, the ID is structured with a leading 1, followed by the Program ID "##," followed by a leading 1, followed by the Contract ID "##." For greater than 99 programs or contracts, a leading 2 would be utilized. |
| Program Engineering Variance Constant2010$M | Current period cost estimate changes from the baseline due to engineering factors (in 2010 constant millions of dollars) |
| ProgramID | ID numbers corresponding to each program |
| ProgramManagerEstimatedPriceAtCompletion$M | Program manager's estimated price at completion (in millions of dollars) |
| PROGRAMNAME | The name generally associated with the program in recent SARs |
| Program Net Cost Variance Constant2010$M | SubtotalCurrentChangesBY$M - Program Schedule Variance BY$M - Program Engineering Variance BY$M. Commonly referred to as Program Cost Variance (or just Cost Variance) in research. |
| Program Schedule Variance Constant2010$M | Current period cost estimate changes from the baseline due to schedule factors (in 2010 constant millions of dollars) |
| RDTE_BasicContractType_CP_D | 1, if FP predominant contract type for RDT&E; 0, otherwise (CP, Cost Plus; or FP, Fixed Price) |
| RDTE_BasicContractType_FP_D | 1, if CP predominant contract type for RDT&E; 0, otherwise (CP, Cost Plus; or FP, Fixed Price) |
| RDTE_CONTOTH_D | 1, if predominant contract type for RDT&E = Hybrid/Other; 0, otherwise |
| RDTE_CPAF_D | 1, if predominant contract type for RDT&E = CPAF; 0, otherwise |
| RDTE_CPFF_D | 1, if predominant contract type for RDT&E = CPFF; 0, otherwise |
| RDTE_CPIF_D | 1, if predominant contract type for RDT&E = CPIF; 0, otherwise |
| RDTE_D | 1, if appropriation is RDT&E; 0, otherwise |
| RDTE_FFP_D | 1, if predominant contract type for RDT&E = FFP; 0, otherwise |
| RDTE_FPIF_D | 1, if predominant contract type for RDT&E = FPIF; 0, otherwise |
| RDTEpredominantBasicContractType | Predominant contract type for RDT&E contracts (CP, Cost Plus; or FP, Fixed Price) |
| SAR_Fractional_Year | Sum of SAR_Year + SAR_Month_12 (NOTE: December 2010 is then represented as 2011.00.) |
| SARBaselineProdEstConstant2010$M | SAR baseline cost estimate through the end of production (in 2010 constant millions of dollars) |
| SubtotalCurrentChangesConstant2010$M | Subtotal of current period cost estimate changes from the baseline (in 2010 constant millions of dollars) |
| TargetCurrentContractPrice$M | Current Target Contract Price (in millions of dollars) |
| TargetInitialContractPrice$M | Initial Target Contract Price (in millions of dollars) |

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# APPENDIX B. NORMALITY OF VARIANCE DATA

For future analysis, particularly SEM, it may be helpful to understand the extent to which the variance data were normally distributed. Figures 16 and 17 are histograms of program schedule variance and contract schedule variance, demonstrating this kurtosis. Each histogram also shows the expected normal distribution of the data, given the sample standard deviation. When interpreting these figures it is useful to note that negative program variances represent better-than-expected performance, while negative contract variances represent poorer-than-expected performance.

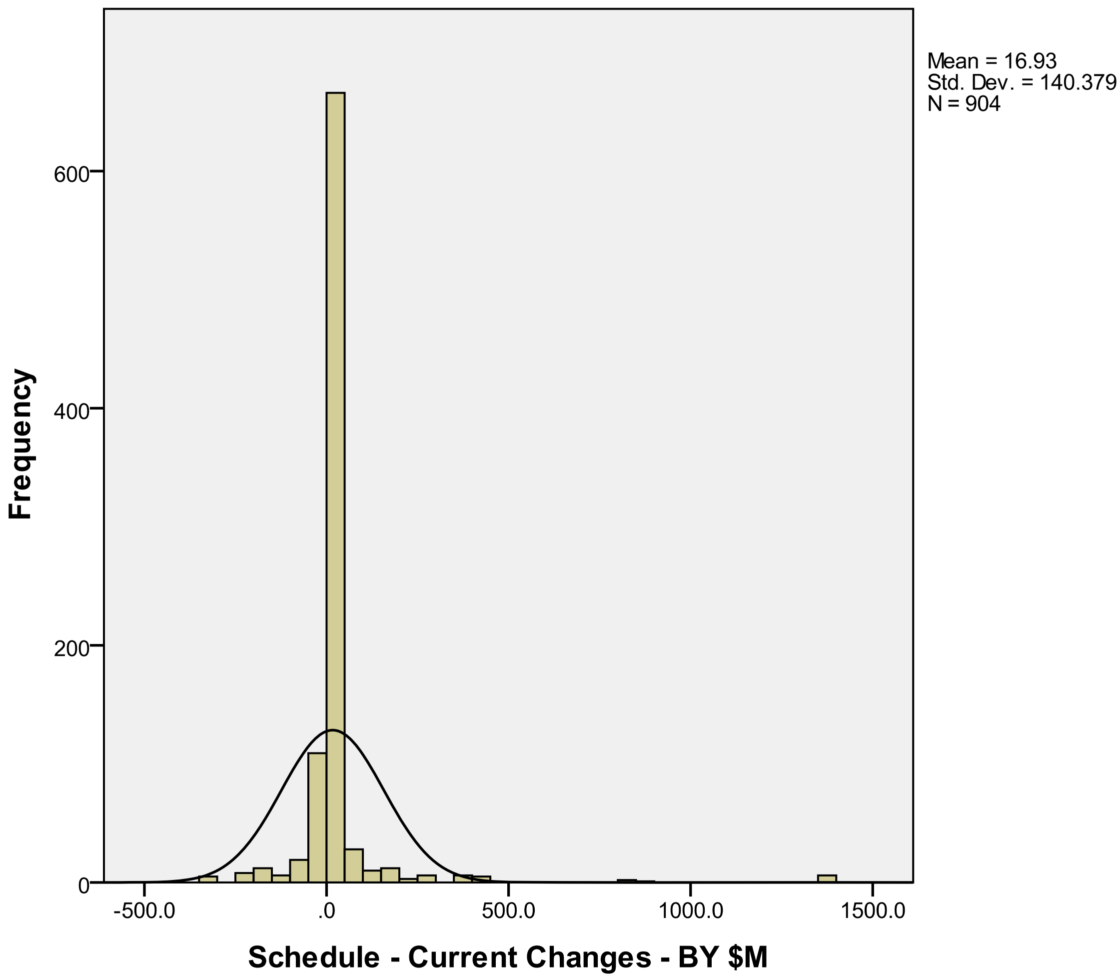


**Figure 16. Program Schedule Variance Histogram With Expected Normal Distribution Overlaid**

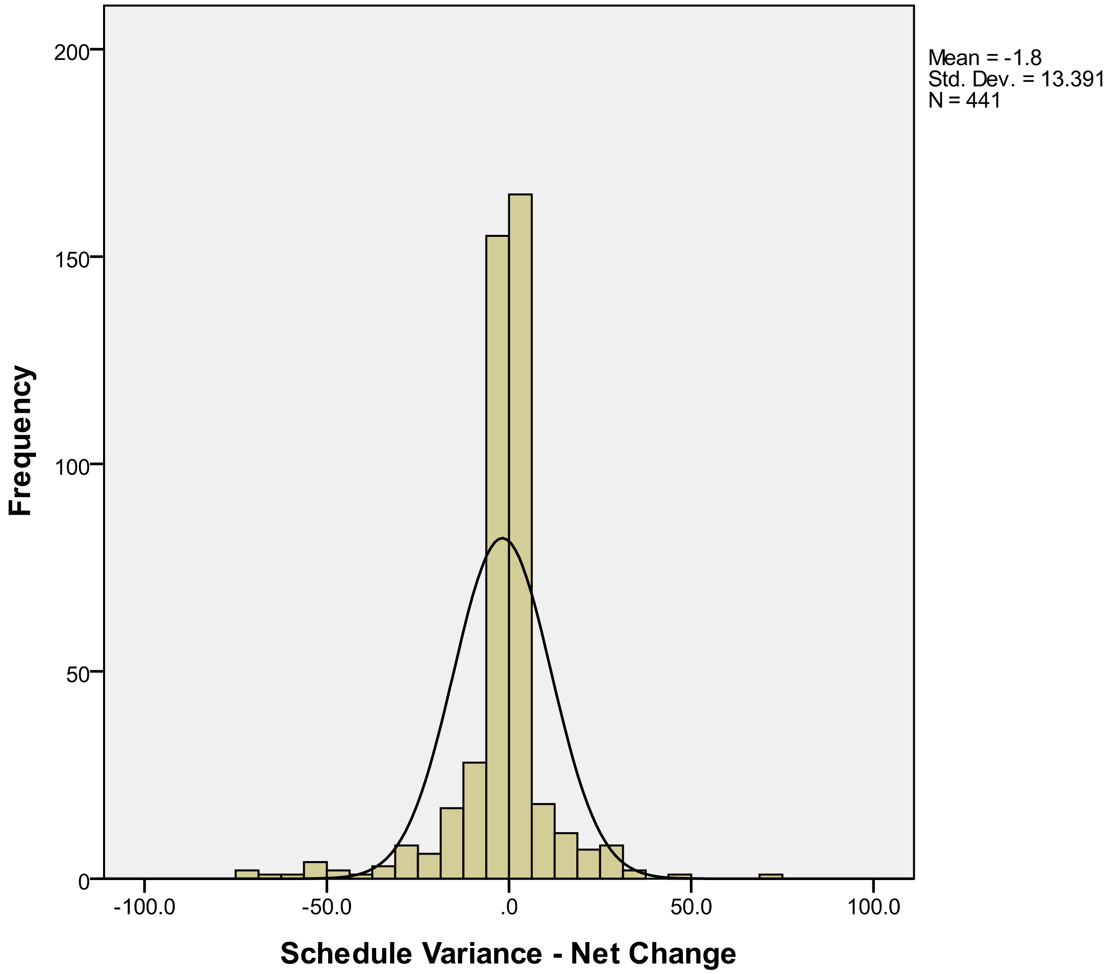


**Figure 17. Contract Schedule Variance Histogram With Expected Normal Distribution Overlaid**

There are two possible explanations for this kurtosis. The first is a failure by program managers and contractors to report undesirable information due to improper incentives corrupting the flow of information from agent to principal at the program and contract levels. The second explanation is that the data represent two separate, overlaid normal distributions. One distribution would represent the typical behavior of programs: incremental failures and successes resulting in relatively small standard deviations and a more compact distribution of results. The other distribution would represent the aberrant behavior of programs: large over- or under-estimation in cost requirements, schedule length, technical maturation, or integration risk. These more unusual events would result in larger standard deviations and a more "flat" distribution of results. It is likely that both explanations are partially responsible for the non-normality present.

Program managers are incentivized to report variances that are advantageous to their program. This leads to a suppression of variances representing poorer-than-expected outcomes due to the subsequent increase in program risk increasing the possibility of program cancellation. Also, variances representing better-than-expected outcomes are suppressed due to the possibility of the program losing funding, thereby precluding technical risk reduction. Program managers are incentivized to think about what is best for their program and Service, while Congress has different goals. Absent perfect incentives, differing objectives result in the agent performing in a manner other than how the principle intended (Laffont & Martimort, 2002). Information can be suppressed by an agent (the program manager) to the extent that information asymmetry exists with the principal (Congress). Congress limits information asymmetry through statutory requirements. Program managers may not necessarily be dishonest in their reporting; willful blindness in the form of excessive pessimism or optimism may also be to blame for near-zero variances. Reporting fewer zero variances would increase the standard deviation of the sample and potentially lower the number of outliers. If outliers found in the data actually represent past variances suppressed to zero or near-zero values, then the standard deviation would not increase, but the amount of kurtosis would decrease.

The second explanation, that the data represent two separate, overlaid normal distributions, is also likely to contribute to the kurtosis. If this is correct, two distributions are represented in the data. One distribution represents the typical behavior of programs—incremental failures and successes resulting in relatively small standard deviations—and another distribution represents the aberrant behavior of programs—large over- or under-estimation in cost requirements, schedule length, technical maturation, or integration risk, resulting in larger standard deviations. Causes for this type of large program or contract variance could be a large over- or under-estimation of the effort required to complete a task, test event failures, poor estimating, or the realization of an accepted risk. Risks assumed by the government, such as integration risk, may play a large part, particularly in dramatic program cost increases. It is likely that both possible causes of the kurtosis are partially responsible for the non-normality present in the data.

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- Contractors in 21$^{st}$-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
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- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

## Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-term Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

## Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness
- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)

- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)
- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
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- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
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